PROGRAM MANAGER FOR ROCKY MOUNTAIN ARSENAL

U.S. ARMY MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

Hydrazine Blending and Storage Facility Interim Response Action

Draft Final Treatment Report

January 7, 1991
Contract Number DAAA15-88-0021
Task IRA H Phase I (Delivery Order 0003)

Harding Lawson Associates

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PREPARED BY

HARDING LAWSON ASSOCIATES

PREPARED FOR

PROGRAM MANAGER FOR ROCKY MOUNTAIN ARSENAL

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THE PURPOSE OF THIS DRAFT FINAL TREATMENT REPORT IS TO DOCUMENT 1) ANALYTICAL METHODS DEVELOPMENT, 2) LABORATORY CERTIFICATION, 3) WASTEWATER TREATMENT, AND 4) AIR MONITORING.

THE REPORT IS DIVIDED INTO THE FOLLOWING SECTIONS:

1. INTRODUCTION - HISTORY OF THE FACILITY, SUMMARY OF THE SCOPE OF WORK, PRIMARY OBJECTIVES OF THE IRA
2. SUMMARY OF PREVIOUS WORK PERTAINING TO THE UV/CHEMICAL OXIDATION PROCESS
3. BENCH/PILOT-SCALE TESTING PROGRAM
4. CHARACTERIZATION OF HYDRAZINE WASTEWATER
5. ANALYTICAL METHODS DEVELOPMENT PROGRAM
6. DESCRIPTION OF FULL-SCALE TREATMENT SYSTEM
7. FULL-SCALE STARTUP TESTING PROGRAM - SAMPLING AND ANALYSIS, OPERATING PROCEDURES, TREATMENT RESULTS
8. SUMMARY OF PHASE I TREATMENT ACTIVITIES.

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EXECUTIVE SUMMARY

This Draft Final Treatment Report has been prepared as an Other Deliverable for Interim Response Action (IRA) H at the Hydrazine Blending and Storage Facility (HBSF) located at Rocky Mountain Arsenal (RMA) in Commerce City, Colorado. It was developed in accordance with requirements set forth in the Federal Facility Agreement (FFA) and the Final Decision Document for the IRA. The HBSF IRA task was separated into two phases that comprise the closure of the HBSF.

Phase I of the HBSF IRA includes analytical methods development and laboratory certification for analysis of hydrazine fuel compounds and n-nitrosodimethylamine (NDMA) in wastewater stored at the HBSF, bench/pilot-scale testing of ultraviolet (UV)/chemical oxidation treatment systems for treatment of hydrazine wastewater, full-scale startup testing of a UV/chemical oxidation treatment system, air monitoring during startup testing, and decommissioning of the HBSF. A brief description of each of these Phase I components follows:

- Analytical methods were successfully developed and certified in accordance with the Program Manager for RMA (PMRMA) laboratory certification program for NDMA, hydrazine, monomethyl hydrazine (MMH), and unsymmetrical dimethyl hydrazine (UDMH). The levels to which methods were certified are adequate to achieve the action level specified in the final Decision Document for UDMH of 25 micrograms per liter (μg/l) and to exceed the Decision Document action level of 20 μg/l for MMH. A technology-based action level was established for hydrazine on the basis of analytical method development and method certification of hydrazine in wastewater at a Certified Reporting Limit (CRL) of 9.9 μg/l. A technology-based action level was established for NDMA at 5 μg/l on the basis of treatment results demonstrated in the startup testing program.

- Bench-scale and pilot-scale testing were performed at the manufacturing facilities of qualified vendors of UV/chemical oxidation systems to evaluate whether currently available technologies are capable of treating the hydrazine wastewater stored at the HBSF to the action levels identified for this IRA. Based on performance results in conjunction with other evaluation criteria, the UV/chemical oxidation system manufactured by Peroxidation Systems, Inc. (PSI), was selected for use in the full-scale startup testing program.

- During full-scale startup testing of the UV/chemical oxidation treatment system, various operating procedures and adjustments involving pretreatment for iron removal, pH, UV intensity, hydrogen peroxide concentration, and treatment time were tested and evaluated. Nine batches (9920 gallons total) were treated using wastewater stored at the HBSF.

- An air-monitoring program was conducted during full-scale startup testing at the hydrazine Wastewater Treatment Facility (WWTF) to monitor and evaluate the integrity of

the UV/chemical oxidation treatment system and to monitor personnel during operation and maintenance of the facility. Several methods for evaluating concentrations of NDMA, hydrazine, MMH, UDMH, and volatile organic compounds (VOCs) in air were utilized.

- Decommissioning will include decontamination, demolition, and reclamation activities at the HBSF as described in the Draft Final Implementation Document for Decommissioning (Phase I) (HLA, 1991). Phase I will conclude with completion of decommissioning activities.

Full-scale treatment and final disposition of the treated wastewater will be described in the Final Implementation Document for Treatment/Disposal (Phase II).

1.0 INTRODUCTION

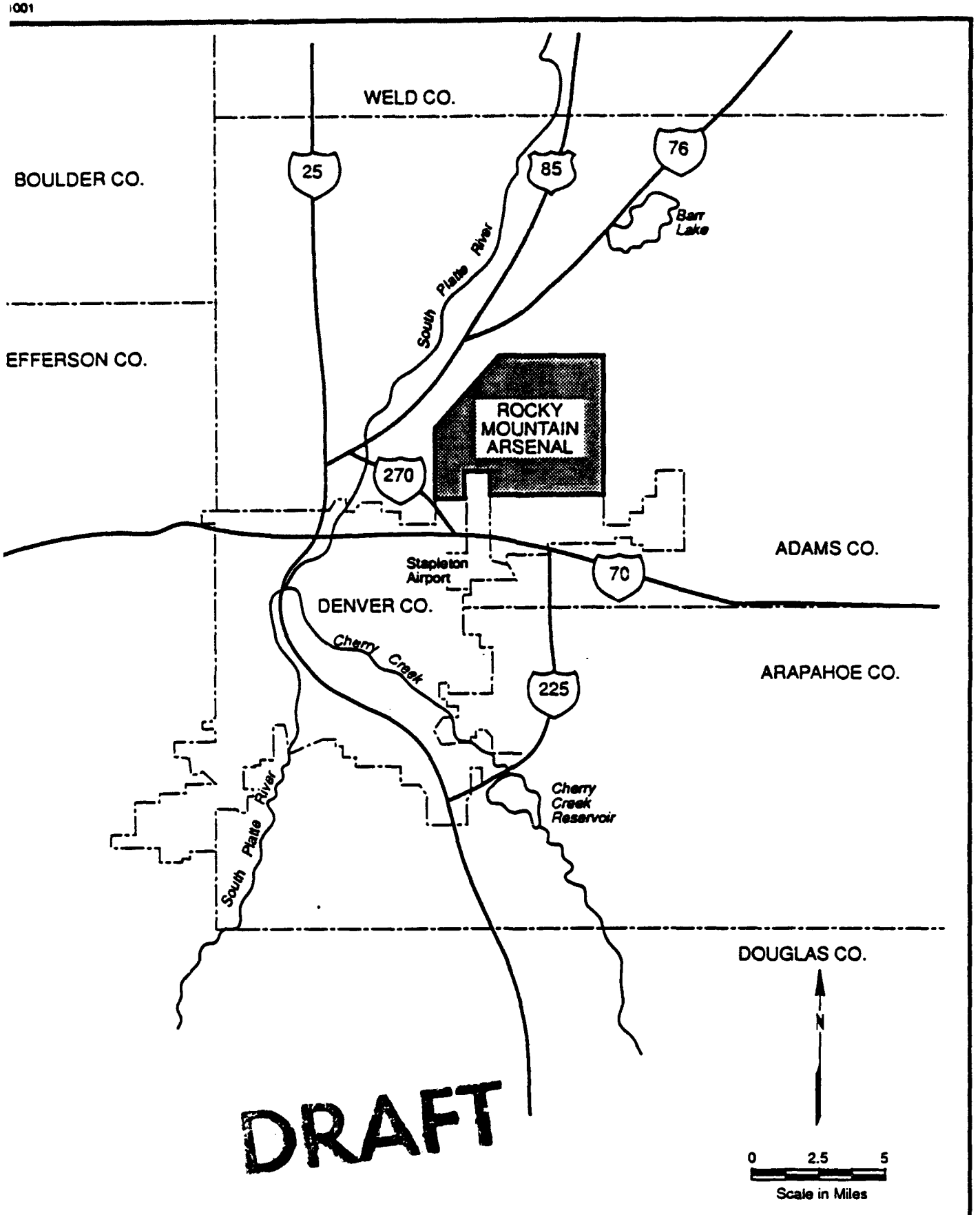
This Draft Final Treatment Report has been prepared as an Other Deliverable for Interim Response Action (IRA) H at the Hydrazine Blending and Storage Facility (HBSF) located at Rocky Mountain Arsenal (RMA) approximately 10 miles northeast of metropolitan Denver, Colorado (Figure 1.1). This report was prepared in accordance with requirements set forth in the Federal Facility Agreement (FFA) and the Final Decision Document for the IRA (Ebasco, 1988).

The purpose of this Draft Final Treatment Report is to document the analytical methods development, laboratory certification, hydrazine wastewater treatment activities, and air monitoring at the HBSF during Phase I of the IRA. This section presents a brief description and history of the HBSF, a summary of the Decision Document, a summary of the scope of work for the IRA, and primary objectives of the IRA. A summary of previous work pertaining to the ultraviolet (UV)/chemical oxidation process for treatment of hydrazine wastewater is included in Section 2.0. Section 3.0 describes the bench/pilot-scale testing program of the UV/chemical oxidation process conducted during Phase I of the IRA. Characterization of the hydrazine wastewater is discussed in Section 4.0. The analytical methods development program is described in Section 5.0. Section 6.0 describes the full-scale treatment facility designed and constructed during Phase I. Sampling and analytical programs, operating procedures, and results of the full-scale startup testing program for treatment of hydrazine wastewater are discussed in Section 7.0. A summary of Phase I treatment activities at the HBSF is provided in Section 8.0.

1.1 BACKGROUND

1.1.1 HBSF History

The HBSF, which was operated by RMA for the U.S. Air Force (USAF) between 1962 and May 1982, is located east of the South Plants area in the northeast corner of Section 1 at RMA (Figure 1.2). The 10-acre site consists of two tank yards, each completely surrounded by security fencing. The yards are connected by two overhead pipelines.



Prepared for:
Program Manager for
Rocky Mountain Arsenal

Commerce City, Colorado

Figure 1.1

RMA LOCATION MAP

RMAB 1003

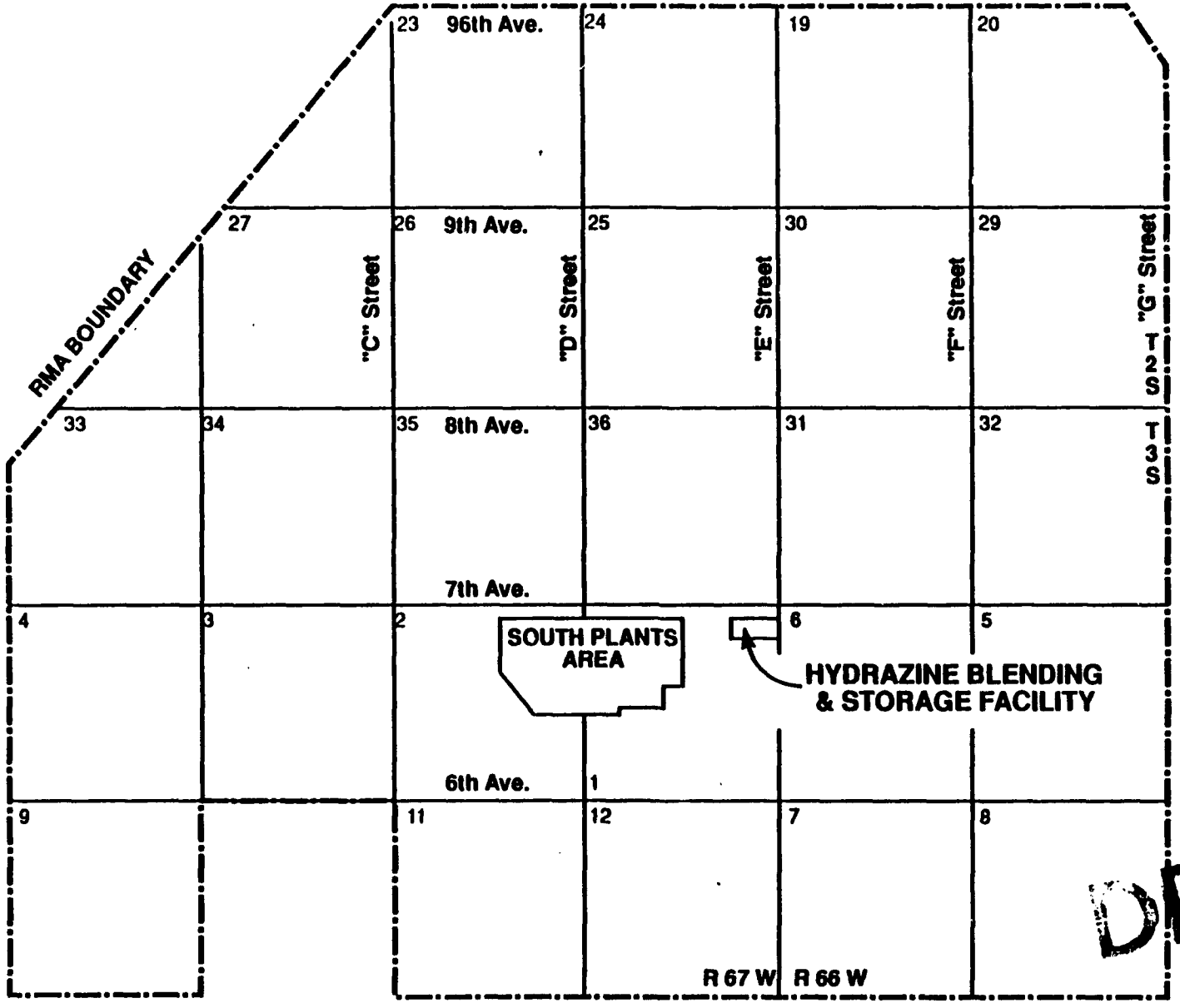


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Figure 1.2

LOCATION OF HYDRAZINE BLENDING AND STORAGE FACILITY AT RMA

The HBSF was used as a depot to receive, blend, store, and distribute hydrazine fuel compounds manufactured elsewhere. The primary operation was blending of anhydrous hydrazine and unsymmetrical dimethyl hydrazine (UDMH) (or 1,1-dimethyl hydrazine) to produce Aerozine 50. Blending operations were not continuous and occurred in response to requests by the USAF. Other operations at the HBSF included loading and unloading of rail cars and tanker trucks, destruction of off-specification Aerozine 50, and storage of Aerozine 50, anhydrous hydrazine, monomethyl hydrazine (MMH), monopropellent hydrazine, hydrazine 70, UDMH, and hydrazine.

Hydrazine and UDMH are unstable in the natural environment and rapidly decompose when exposed to the atmosphere. One of the decomposition products of UDMH is n-nitrosodimethylamine (NDMA), a suspected human carcinogen. From January through March 1982, the U.S. Occupational Safety and Health Administration (OSHA) surveyed the HBSF and detected the presence of airborne NDMA within the HBSF. In May 1982, RMA ceased operations and closed the HBSF to all but safety-essential or emergency-response entries.

Following the discontinuation of operations at the HBSF, tanks that were used to store hydrazine fuel compounds were decontaminated. The decontamination procedure consisted of pumping a sodium hypochlorite solution through horizontal hydrazine fuel storage tanks HAS-1, HAS-2, HAS-3, CS-1, US-1, and US-2 located at the west area of the HBSF. The decontamination solution was subsequently pumped into tanks US-3 and US-4 located at the east area of the HBSF. In addition, an in-ground concrete sump located in the west area of the HBSF received water used to decontaminate various portions of the HBSF (Figure 1.3). Secondary containment structures associated with hydrazine fuel storage tanks HAS-1, HAS-2, HAS-3, CS-1, US-1, and US-2 are connected to the in-ground concrete sump via buried pipelines. Volumes of wastewater currently stored in tanks US-3, US-4, and the in-ground concrete sump are approximately 50,000 gallons, 200,000 gallons, and 40,000 gallons, respectively.

On February 1, 1988, a proposed Consent Decree was filed in the case of *U.S. v. Shell Oil Company* with the U.S. District Court in Denver, Colorado. A modified version of the Consent

RMAH 1005

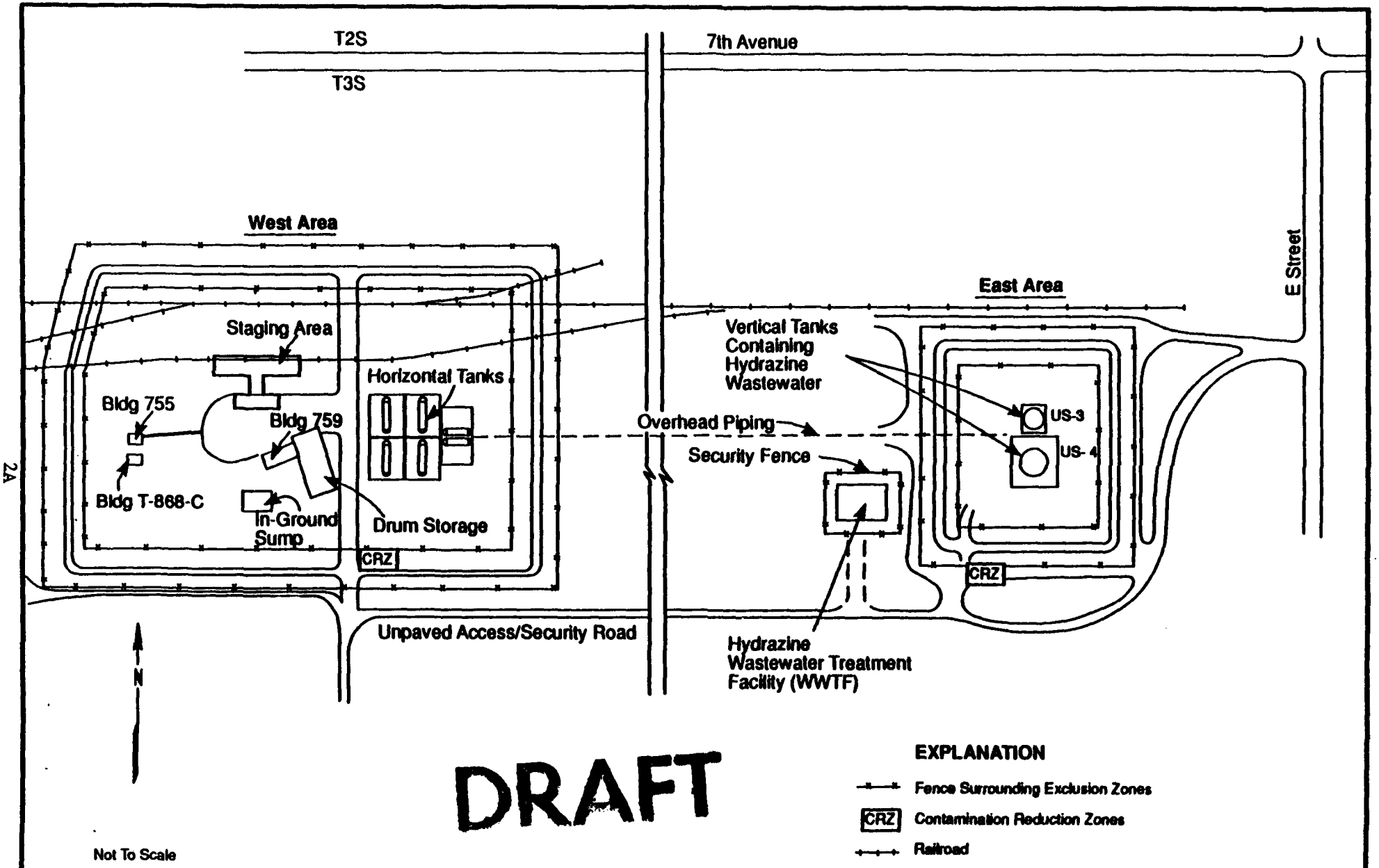

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Figure 1.3

HYDRAZINE BLENDING AND STORAGE FACILITY MAP

Decree was filed on June 7, 1988. On February 17, 1989, an FFA that incorporates the provisions of the modified Consent Decree was executed by the U.S. Department of the Army (Army), Shell Oil Company, the U.S. Environmental Protection Agency (EPA), the U.S. Department of the Interior (DOI), the U.S. Department of Justice (DOJ), and the U.S. Department of Health and Human Services (DHHS). The FFA specifies a number of IRAs, including Closure of the HBSF, as necessary and appropriate before final remedial action at RMA.

1.1.2 Decision Document

In October 1988, the Final Decision Document for the IRA was released by the Program Manager for RMA (PMRMA). The Decision Document states that the HBSF IRA is to meet the following specific criteria:

- Treat wastewater to levels that will effectively eliminate any substantial risks to human health and the environment associated with the contaminants of concern, including hydrazine, MMH, UDMH, and NDMA
- Use treatment technology that is technically feasible and readily implementable
- Achieve permanent remediation through destruction of contaminants of concern to designated action levels or reduce the toxicity, mobility, or volume of wastewater
- Be cost-effective
- Comply with designated applicable or relevant and appropriate requirements (ARARs) to the maximum extent practicable

The Decision Document further states that ARARs and action levels specifying cleanup levels protective of human health and the environment, if pertinent, need to be identified and applied. The following action levels were identified in the Decision Document for the IRA:

Compound	Action Level
NDMA	To be determined after further testing (as close to 1.4 parts per trillion [ppt] as possible)
Hydrazine	2.5 parts per billion (ppb)
MMH	20 ppb
UDMH	25 ppb

In examining hydrazine wastewater treatment alternatives in the Decision Document, the No Action alternative was dismissed as unacceptable because it would not provide any remediation

of the HBSF or reduce levels of NDMA. Of the 17 wastewater treatment alternatives considered, 11 were eliminated early in the evaluation process based on technical factors. The following six alternatives, identified as meeting treatment efficiency and implementation requirements, were further considered:

1. UV light/chlorination
2. Ozonation
3. Evaporation pond
4. Offsite incineration
5. UV light/ozone
6. UV light/hydrogen peroxide

Because the technical feasibility and treatment costs of the UV light/ozone and UV light/hydrogen peroxide alternatives were similar, the Decision Document stated that either alternative would be used for treating the hydrazine wastewater. It was further explained in the Decision Document that the final selection between these two alternatives should be based on more detailed engineering designs and cost estimates.

Bench/pilot-scale testing of one UV light/ozone treatment system and one UV light/hydrogen peroxide treatment system as well as one UV light/ozone plus hydrogen peroxide treatment system conducted during Phase I of this IRA resulted in the selection of the UV/hydrogen peroxide system for full-scale startup testing (See Section 3.0).

1.2 SCOPE OF WORK/OBJECTIVES

The HBSF IRA task was separated into two phases that comprise the closure of the HBSF. Phase I included planning, wastewater treatment system selection and modification (including bench/pilot-scale testing), full-scale system installation, analytical method development and laboratory method certification, treatment system startup testing, and development of a Draft Final Implementation Document. Phase I will also involve decontamination, dismantling, and disposal of structures and equipment at the HBSF (decommissioning).

Consistent with the overall IRA objectives cited in the Final Decision Document, the following specific objectives were developed for Phase I:

- Conduct a bench-scale testing program to evaluate whether qualified manufacturers of UV/chemical oxidation equipment could reduce concentrations of hydrazine fuel compounds (hydrazine, UDMH, MMH, and NDMA) in wastewater stored at the HBSF to near the action levels identified in the Final Decision Document
- Select an appropriate UV/chemical oxidation treatment system for treatment of hydrazine wastewater stored at the HBSF
- Evaluate necessary treatment system modifications to achieve the desired discharge concentrations for chemicals of concern in the wastewater
- Develop and certify an analytical method for analysis of NDMA in treated wastewater to attain the lowest technologically achievable Certified Reporting Limit (CRL)
- Design and construct a full-scale UV/chemical oxidation treatment system and conduct full-scale startup testing using approximately 10,000 gallons of the hydrazine wastewater
- Gather sufficient process information from the startup testing to more specifically define operational treatment requirements to predict treatment time necessary to achieve action levels identified in the Decision Document
- Prepare a Draft Final Implementation Document for (1) decommissioning of the HBSF (Phase I) (HLA, 1991) and (2) treatment and disposal of remaining hydrazine wastewater at the HBSF (Phase II)
- Decontaminate, dismantle, and dispose structures, piping, and equipment at the HBSF

2.0 SUMMARY OF PREVIOUS WORK - TREATMENT OF HYDRAZINE WASTEWATER VIA UV/CHEMICAL OXIDATION PROCESSES

The technical feasibility and treatment efficiency of UV/chemical oxidation processes are described in the Final Decision Document for the IRA. Destruction of contaminants in UV/chemical oxidation treatment systems is accomplished by (1) photolysis via UV irradiation, (2) chemical oxidation by the hydrogen peroxide or ozone and hydroxyl radicals, which are strong oxidizers produced during photolysis, and (3) the synergistic effects of both the chemical oxidant and the UV light. The following sections summarize previous work documented in literature relative to the use of UV/chemical oxidation processes to treat hydrazine fuel compounds.

2.1 USAF STUDIES

The utilization of UV light to enhance chemical oxidation as a treatment process for the destruction of hydrazine fuel compounds and NDMA was evaluated by the USAF Systems Command Civil and Environmental Engineering Development Office (CEEDO, 1978) and the Illinois Institute of Technology Research Institute (IITRI, 1986 and 1988a) under contract to the USAF. The CEEDO research addressed treatment of aqueous solutions of hydrazine fuel compounds using ozone. It attempted to establish the stoichiometry and kinetics of chemical oxidation by ozone for hydrazine solutions, identify the partial oxidation products from the oxidation process, and establish the toxicity of treated effluent using fathead minnows and *daphnia magna.*

The conclusions derived from the CEEDO research were (1) increasing solution pH increases the rate of ozone oxidation of hydrazine fuel compounds, (2) increasing specie concentration increases the required hydraulic detention times, (3) increasing the ozone partial pressure decreases the required treatment times for hydrazine fuel compounds, (4) UV light acts as a catalyst and reduces the treatment times for hydrazine fuel compounds, (5) ozonation does reduce the toxicity of the hydrazine fuel compounds but significant toxicity still exists in the reaction mixtures, and (6) ozonation of MMH and UDMH in an alkaline solution results in several

intermediate products that present discharge problems for treated effluent as a result of organic loading or toxicity.

IITRI worked with the USAF to develop a method to treat wastewater containing hydrazine fuel compounds and associated degradation byproducts, such as NDMA. Evaluation of potential methods identified chemical oxidation as a technically feasible and potentially cost- effective approach. Ozone, ozone/UV light, and ozone/chlorine were selected by IITRI for testing as oxidizing agents on both the bench and pilot scale. Findings of the study include the following: (1) hydrazine fuel compounds are oxidized rapidly to below detectable limits when treated by ozone or ozone/UV light and (2) the presence of UV radiation enhances the overall destruction of NDMA.

2.2 IITRI EXPERIMENTS

PMRMA contracted with IITRI to investigate UV/chemical oxidation processes for the destruction of hydrazine fuel compounds and NDMA. The purpose of the testing was to evaluate whether these processes could destroy the compounds in a reasonable amount of time.

Hydrogen peroxide and UV light, combined as a treatment process, were utilized in experiment No. 2 (IITRI, 1987). The experiment was conducted using a several-fold increase (over the stoichiometric value) of hydrogen peroxide combined with UV light at a wavelength of 245 nanometers (nm). During the experiment, hydrogen peroxide was added to maintain a relatively constant concentration. The pH was also maintained in the range of 9.8 to 10.03 via sodium hydroxide addition.

Results of the treatment experiment showed that hydrazine fuel compounds were destroyed at a rapid rate initially, but that the destruction rate decreased as the concentration of hydrazine fuel compounds decreased. Based on these experimental results, IITRI concluded that the reaction rate for destruction of hydrazine fuel compounds is kinetically controlled and is proportional to the initial concentration of the hydrazine fuel compounds. The NDMA concentration remained high (greater than 1 ppm) for the first two days of the experiment and then began to decrease rapidly at approximately the time when the concentration of hydrazine was at its lowest

(0.0020 ppm). From this information, it was concluded that during the UV/chemical oxidation process, hydrazine is decomposed before NDMA destruction.

There was some evidence from previous studies (IITRI, 1988a) that iron will complex with the precursors of NDMA and will gradually release them as decomposition proceeds, thereby increasing the required time for treatment. A treatment experiment was conducted using ozone and UV light (245 nm) in which iron was precipitated by the addition of sodium sulfide. Results of this experiment were compared to an experiment using ozone and UV light with no iron removal. In the absence of iron, NDMA decomposed at a faster rate and to a lower concentration, supporting the previously performed studies. Metal ions, including the ferric ion, will catalyze the oxidation of hydrazine fuel compounds but retard the destruction of NDMA, especially at levels less than 1 microgram per liter (μg/l).

The IITRI experiments indicated that the UV/chemical oxidation process is capable of decomposing hydrazine fuel compounds and nitrosamines to low levels in a reasonable amount of time.

2.3 FIELD PILOT-SCALE TREATABILITY STUDIES

The U.S. Army Engineer Waterways Experiment Station (WES) conducted field pilot-scale treatability studies using wastewater that contained hydrazine, MMH, UDMH, and NDMA. These treatability studies were conducted to provide treatment performance data for the UV/chemical oxidation process and for the design of a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) wastewater treatment system (CWTS) (WES, 1989).

Treatability studies were conducted whereby the pH of the wastewater was adjusted with low (250 to 500 mg/l) doses of hydrogen peroxide and high (>500 mg/l) doses of hydrogen peroxide and compared to runs where pH was not adjusted. In the treatability studies in which pH was not adjusted, the following were noted:

- The NDMA concentration decreased to approximately 0.1 milligram per liter (mg/l), with contact times between five and nine minutes in both low and high hydrogen peroxide dose runs. The data indicated an increase in NDMA concentration in the high hydrogen peroxide dose run at 18 minutes of contact time.

- The low hydrogen peroxide dose appeared to be the most effective with respect to rapid contaminant destruction.
- MMH and hydrazine were gradually destroyed as contact time increased.
- Hydrazine fuel compounds appear to have been more effectively destroyed during the high hydrogen peroxide dose runs, indicating that hydrazine fuel destruction is not UV-limited.
- UDMH was rapidly destroyed to approximately 5 mg/l with a contact time of approximately nine minutes in the high hydrogen peroxide dose run. UDMH destruction continued at a more gradual rate during the run of 18 minutes contact time.

A contact time of approximately 18 minutes was used in the pH-adjusted runs. Hydrazine and UDMH were more effectively destroyed during the low hydrogen peroxide dose pH-adjusted run than during the non-pH-adjusted runs with high hydrogen peroxide doses. The data developed by WES did not clearly indicate that pH adjustment significantly affects the destruction efficiency for hydrazine fuel compounds and NDMA because the initial concentrations of contaminants varied widely between the pH-adjusted and non-pH-adjusted runs.

The pilot studies conducted by WES also evaluated the effectiveness of hydrazine fuel compound destruction with and without the use of a catalyst. Bench-scale laboratory studies previously conducted by Peroxidation Systems, Inc., (PSI) for WES indicated that the destruction rates for hydrazine fuel compounds would be accelerated by the use of a proprietary catalyst. Pilot-scale runs were performed in the field by WES utilizing wastewater from the HBSF to confirm the bench-scale laboratory results with respect to use of a catalyst and to evaluate whether the overall effectiveness of the pilot-scale UV/chemical oxidation equipment might reduce the need for a catalyst. Because the catalyst was proprietary to PSI, it was desirable to minimize its use so that PMRMA would not be limited to a single source for procurement of the process chemical. WES concluded from the pilot studies that the use of the catalyst reduced the treatment times required for the hydrazine wastewater stored at the HBSF. Reduced treatment times would result in lower operating costs, even with the use of a proprietary catalyst.

3.0 BENCH/PILOT-SCALE TESTING PROGRAM

From April through August 1989, a bench/pilot-scale testing program was conducted. Information from UV/chemical oxidation equipment manufacturers regarding the treatment of wastewater containing hydrazine fuel compounds and NDMA was limited. Thus, the primary objective of the bench/pilot-scale treatability testing was to evaluate whether qualified manufacturers of UV/chemical oxidation equipment could reduce the concentrations of hydrazine fuel compounds and NDMA in wastewater stored at the HBSF to near the action levels identified in the Decision Document. A secondary objective of the bench/pilot-scale testing program was to generate design and operational information for subsequent use during full-scale UV/chemical oxidation treatment system selection and design/construction.

Bench- and pilot-scale testing were performed at the manufacturing facilities of three qualified vendors of UV/chemical oxidation equipment using wastewater samples collected from tank US-4 at the HBSF. Hydrazine wastewater was collected, sampled, and shipped in stainless-steel drums to three vendors. PSI and ULTROX International performed bench-scale testing and SolarChem Environmental Systems, Inc., performed pilot-scale testing of their respective UV/chemical oxidation equipment. Analytical testing of both untreated and treated wastewater was performed by an independent laboratory to evaluate treatment efficiency of the three vendors' equipment. Visits were made to each vendor's manufacturing facility during the treatability testing to witness the testing and assess each manufacturer's capabilities.

3.1 BENCH/PILOT-SCALE ANALYTICAL PROGRAM

During the bench/pilot-scale testing program, influent, process effluent, and final effluent wastewater samples were analyzed to evaluate the efficiency of each vendor's technology to treat hydrazine fuel compounds, NDMA, and other organic compounds in the HBSF wastewater. Wastewater samples were analyzed for organic and inorganic parameters, including hydrazine fuel compounds (hydrazine, MMH, and UDMH), NDMA, purgeable halocarbons, volatile organic compounds (VOCs), semivolatile organic compounds, pesticides/polychlorinated biphenyls (PCBs),

and metals. Analytical results of an influent wastewater sample served as the influent baseline for all three vendors.

Table 3.1 presents a summary of analytical methods used for analysis of wastewater samples and compounds analyzed by each method. Analyses of wastewater samples for the hydrazine fuel compounds and NDMA were conducted by developmental analytical methods. Analysis of wastewater samples for NDMA was conducted according to a method developed by IITRI using a modified EPA Method 607. Analysis of hydrazine fuel compounds, including hydrazine, UDMH, and MMH, was conducted using methods developed by Engineering-Science (ES, 1988). The remaining compounds listed in Table 3.1 were analyzed by standard EPA methods. Purgeable halocarbons were analyzed by EPA Method 601. VOCs were analyzed by gas chromatography/ mass spectrometry (GC/MS) by EPA Method 8240. Semivolatiles were analyzed by GC/MS by EPA Method 8270, and pesticides and PCBs were analyzed by GC/electron capture detector (ECD) by EPA Method 8080. Metals were analyzed by the EPA 200 series methods.

In utilizing developmental methods for analysis of hydrazine fuel compounds in wastewater, it was necessary to establish method detection limits (MDLs) for NDMA, hydrazine, MMH, and UDMH. As defined by EPA, MDLs are established for each analyte of interest by statistically calculating the minimum concentration that can be identified, measured, and reported with 99 percent confidence to be greater than zero. Consistent with EPA procedures, MDLs were established for the hydrazine fuel compounds in analyte-free, reagent-grade water to achieve the lowest technologically achievable limits by eliminating matrix interference effects.

Because most environmental samples are not analyte-free, matrix interference effects are common and MDLs are not achieved for analysis of most sample types. In cases where matrix interferences are observed, it is necessary to establish method reporting limits (MRLs) for the matrix and medium of concern. The MRL is an attempt to establish a reporting limit that can be reliably and routinely achieved by a given laboratory for a sample of a given medium under specific environmental conditions. Consequently, MRLs represent higher reporting limits than MDLs.

Table 3.1: Summary of Analytical Methods and Target Parameters for Analysis of Wastewater Samples - Bench/Pilot-Scale Testing Program
(Page 1 of 4)

Analytical Method	Target Parameters
EPA Method 607[1]	N-nitrosodimethylamine (NDMA)
GC/NPD and/or GC/FID[1]	Hydrazine Fuels Hydrazine Monomethyl hydrazine (MMH) Unsymmetrical dimethyl hydrazine (UDMH)
EPA Method 601[1]	Purgeable Halocarbons Carbon tetrachloride Chlorobenzene Chloroethane Chloroform Chloromethane 1,1-Dichloroethane 1,2-Dichloroethane 1,1-Dichloroethene trans-1,2-Dichloroethene Methylene chloride Tetrachloroethene 1,1,1-Trichloroethane 1,1,2-Trichloroethane Trichloroethene
EPA Method 200	Metals Total antimony Total arsenic Total barium Total beryllium Total cadmium Total chromium Total cobalt Total copper Total iron Total lead Total mercury Total molybdenum Total nickel Total selenium Total silver Total thallium Total vanadium Total zinc

Table 3.1: (Page 2 of 4)

Analytical Method	Target Parameters
EPA Method 8080	Organochlorine Pesticides and PCBs Aldrin a-BHC b-BHC d-BHC g-BHC (Lindane) Chlordane 4,4'-DDD 4,4'-DDE 4,4'-DDT Dieldrin Endosulfan I Endosulfan II Endosulfan sulfate Endrin Endrin aldehyde Heptachlor Heptachlor epoxide Methoxychlor Toxaphene PCB-1016 PCB-1221 PCB-1232 PCB-1242 PCB-1248 PCB-1254 PCB-1260
EPA Method 8240	Volatile Organic Compounds Acetone Benzene Bromodichloromethane Bromoform Bromomethane 2-Butanone Carbon disulfide Carbon tetrachloride Chlorobenzene Chloroethane 2-Chloroethyl vinyl ether Chloroform Chloromethane Dibromochloromethane 1,1-Dichloroethane 1,2-Dichloroethane 1,1-Dichloroethene trans-1,2-Dichloroethene 1,2-Dichloropropane cis-1,3-Dichloropropene

Table 3.1: (Page 3 of 4)

Analytical Method	Target Parameters
EPA Method 8240 (Continued)	Volatile Organic Compounds (Continued) trans-1,3-Dichloropropene Ethyl benzene 2-Hexanone Methylene chloride 4-Methyl-2-pentanone Styrene 1,1,2,2-Tetrachloroethane Tetrachloroethene Toluene 1,1,1-Trichloroethane 1,1,2-Trichloroethane Trichloroethene Trichlorofluoromethane Vinyl acetate Vinyl chloride Total xylenes
EPA Method 8270	Semivolatile Organic Compounds Acenaphthene Acenaphthylene Anthracene Benzidine Benzo (a) anthracene Benzo (b) fluoranthene Benzo (k) fluoranthene Benzo (g,h,i) perylene Benzo (a) pyrene Benzoic acid Benzyl alcohol 4-Bromophenyl-phenylether Butylbenzylphthalate di-n-Butylphthalate 4-Chloroaniline bis(2-Chloroethoxy)methane bis(2-Chloroethyl)ether bis(2-Chloroisopropyl)ether 4-Chloro-3-methylphenol 2-Chloronaphthalene 2-Chlorophenol 4-Chlorophenyl-phenylether Chrysene Dibenzo(a,h)anthracene Dibenzofuran 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene 3,3'-Dichlorobenzidine 2,4-Dichlorophenol

Table 3.1: (Page 4 of 4)

Analytical Method	Target Parameters
EPA Method 8270 (Continued)	Semivolatile Organic Compounds (Continued) Diethylphthalate 2,4-Dimethylphenol Dimethyl phthalate 4,6-Dinitro-2-methylphenol 2,4-Dinitrophenol 2,4-Dinitrotoluene 1,2-Diphenylhydrazine bis(2-Ethylhexyl)phthalate Fluoranthene Fluorene Hexachlorobutadiene Hexachlorobenzene Hexachlorocyclopentadiene Hexachloroethane Indeno(1,2,3-cd)pyrene Isophorone 2-Methylnaphthalene 2-Methylphenol 4-Methylphenol Naphthalene n-Nitrosodimethylamine 2-Nitroaniline 3-Nitroaniline 4-Nitroaniline Nitrobenzene 2-Nitrophenol 4-Nitrophenol n-Nitrosodiphenylamine n-Nitroso-di-n-propylamine di-n-Octyl phthalate Pentachlorophenol Phenanthrene Phenol Pyrene 1,2,4-Trichlorobenzene 2,4,5-Trichlorophenol 2,4,6-Trichlorophenol

[1] Method requires laboratory certification for analysis of final treated samples during effluent startup testing operation

DDD = 2,2-bis(para-chlorophenyl)-1,1-dichloroethane
DDE = 2,2-bis(para-chlorophenyl)-1,1-dichloroethene
DDT = 2,2-bis(para-chlorophenyl)-1,1,1-trichloroethane
EPA = U.S. Environmental Protection Agency
GC/NPD = gas chromatography/nitrogen phosphate detector
GC/FID = gas chromatorgaphy/flame ionization detector
PCB = polychlorinated biphenyl
BHC = hexachlorocyclohexane

As in the case with the analysis of hydrazine wastewater samples, matrix interference effects were significant, and MDLs were not achievable for most samples analyzed. As determined, the MRLs represent the lowest technologically achievable reporting limits for NDMA and the hydrazine fuel compounds. Consequently, MRLs are referred to throughout this section and subsequent sections of this document where results for analyses conducted by developmental methods and methods not certified under the PMRMA laboratory certification program are reported. Analytical methods for analysis of NDMA and the hydrazine fuel compounds were later certified and CRLs established by PMRMA as discussed in Section 5.3.

3.2 BENCH/PILOT-SCALE TESTING PROGRAM EVALUATION

Each of the three vendors performed several preliminary treatability runs using the hydrazine wastewater. The purpose for the preliminary runs was for each vendor to develop and optimize the operating conditions for its equipment to effect the best removal performance with respect to the hydrazine fuel compounds and NDMA. After the preliminary runs were completed, each vendor conducted the final treatability run that served as the basis for evaluation of its performance and selection for this application. The final treatability runs that were evaluated with respect to removal performance for the hydrazine fuel compounds and NDMA were Run 8 for PSI, Run 5 for SolarChem Environmental Systems, and Run 6 for ULTROX International. The analytical results for the preliminary and final treatability runs conducted by the three vendors during the bench/pilot-scale testing program are included in Appendix A.

The results of the final treatability runs show that the hydrazine fuel compounds were reduced to below MRLs, with the exception of hydrazine and UDMH for one vendor. NDMA was removed to less than 0.2 μg/l in the final treatability runs. Because analytical methods were developmental and reporting limits had not been previously established, the MRLs established during this program were considered the lowest technologically attainable limits that could be reliably and routinely achieved for the hydrazine wastewater matrix. Because these MRLs for the hydrazine fuel compounds and NDMA established during the bench/pilot-scale testing program

were higher than the action levels identified in the Decision Document, the Decision Document action levels could not be demonstrated during the bench/pilot-scale testing program.

The selection of PSI to provide the UV/chemical oxidation equipment was based in part on the analytical results from final treatability runs during the bench/pilot-scale testing program. Other evaluation criteria were also considered, including capital and projected operating costs, potential for generation of a hazardous offgas, ease of installation and operation, experience, delivery time, and anticipated response and support service. Vendors were evaluated relative to those criteria on the basis of the vendor treatability test reports and visits to the vendor facilities during testing.

4.0 CHARACTERIZATION OF HYDRAZINE WASTEWATER

Before it initiated the full-scale startup testing program, the Army characterized the chemical constituents in hydrazine wastewater stored in tanks US-3 and US-4 and the in-ground concrete sump.

Nine investigative samples and three duplicate samples were collected during January 1990 from tanks US-3 and US-4 and the in-ground concrete sump for chemical characterization. Samples were collected from various depth intervals in the tanks to provide adequate characterization. Samples were collected from tank US-3 at 4.5, 9.5, and 14.5 feet below the liquid surface. Samples were collected from tank US-4 at 5, 15, and 25 feet below the liquid surface. Samples were collected from the in-ground concrete sump at 1, 2, and 4.5 feet below the liquid surface. Duplicate samples were collected from a single sampling interval in each tank for evaluation of analytical reproducibility.

Each of the 12 hydrazine wastewater samples collected from the tanks and the in-ground sump were analyzed for NDMA, hydrazine fuel compounds (hydrazine, UDMH, and MMH), priority pollutant list VOCs, priority pollutant list semivolatile organic compounds (SVOCs), priority pollutant list pesticides/PCBs, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), and priority pollutant list metals (plus iron) listed in the draft National Pollutant Discharge Elimination System (NPDES) discharge permit for the RMA Sanitary Wastewater Treatment Plant (STP). Samples were also analyzed for the RMA-related compounds (organophosphorus pesticides, organosulfur compounds, dibromochloropropane [DBCP], diisopropylmethylphosphonate [DIMP], dimethylmethylphosphonate [DMMP], and dicyclopentadiene [DCPD]).

Appendix A is a tabular summary of the analytical results of the investigative wastewater samples. Table 4.1 summarizes the concentration ranges of analytes detected above the MRL in wastewater samples collected from the tanks and the in-ground sump. Analytes listed in Appendix A but not listed in Table 4.1 were not detected in wastewater samples.

Table 4.1: Concentration Ranges of Analytes Detected in Hydrazine Wastewater Samples from Rocky Mountain Arsenal
(Page 1 of 2)

Analyte	Tank US-3 (µg/l)	Tank US-4 (µg/l)	In-Ground Sump (µg/l)
Hydrazine Fuel Compounds/NDMA			
Hydrazine	22,000 - 60,000	79,000 - 1,100,000	380 - 2100
Monomethyl hydrazine	50,000 - 94,000	140,000 - 180,000	ND
Unsymmetrical dimethyl hydrazine	53,000 - 110,000	790,000 - 1,100,000	85 - 1600
n-Nitrosodimethylamine	500 - 790	53 - 60	1.4 - 5.8
Volatile Organic Compounds			
Acetone	50.7	23.8 - 32.0	ND
Benzene	53 - 112	2.25 - 2.66	ND
Chlorobenzene	41.6	ND	ND
Chloroethane	2000	ND	ND
Chloroform	3000 - 4750	96.6 - 106	ND
Chloromethane	45.3	7.25 - 25.6	ND
1,2-Dichloroethane	66 - 143	1.61 - 1.67	ND
1,1-Dichloroethane	96 - 570	3.66 - 3.89	ND
1,1-Dichloroethene	13.1	ND	ND
1,2-Dichloropropane	26.0 - 89.1	ND	ND
Dimethyl sulfide	4.87 - 14.2	46 - 61	ND
Methylethyl ketone	ND	ND	13.3
Methylene chloride	2600 - 13,000	61 - 110	ND
o,p-Xylene	1.84	ND	ND
Tetrachloroethene	2.60	ND	ND
Toluene	5.09	ND	96 - 680
Trichloroethene	5.16	ND	ND
Vinyl acetate	134 - 186	ND	ND
Vinyl chloride	78.3	ND	ND
Semivolatile and Pesticide Compounds			
Aniline	1200 - 1460	1500 - 6400	ND
Atrazine	33.1 - 44.0	4.52 - 5.50	8.86 - 150
Benzothiazole	2.47 - 2.92	2.97 - 14.9	ND
4-Chloroaniline	ND	2.88 - 2.94	ND
Malathion	ND	ND	0.574
4-Methylphenol	ND	ND	45.5 - 320
Naphthalene	8.18 - 9.68	ND	ND
Parathion	ND	ND	3.78
Phenol	ND	ND	4.12 - 4.52
Vapona	19.1	ND	ND
bis(2-Ethylhexyl) phthalate	2.00	11.0	2.14

Table 4.1: (Page 2 of 2)

Analyte	Tank US-3 (µg/l)	Tank US-4 (µg/l)	In-Ground Sump (µg/l)
Metals			
Arsenic	43.1 - 66.3	16.1 - 20.4	220 - 288
Cadmium	ND	ND	0.601 - 1.88
Chromium	5.22 - 6.87	6.62 - 7.61	5.8 - 10.7
Copper	7.48	ND	ND
Iron	48 - 81,000	6330 - 12,100	700 - 1080
Mercury	0.738 - 0.868	0.241 - 0.658	ND
Silver	0.462	0.224	ND
Zinc	12.2 - 28.9	12.4 - 22.8	24.6 - 55.4

µg/l = micrograms per liter
ND = not detected at or above the method reporting limit
NDMA = n-nitrosodimethylamine

20003,620.10 - TR
1226010491

5.0 ANALYTICAL METHODS DEVELOPMENT FOR THE FULL-SCALE STARTUP TESTING PROGRAM

To reliably demonstrate that treatment of NDMA and hydrazine fuel compounds meets the IRA action levels or the lowest technologically achievable levels, it was necessary to develop and certify analytical methods for these compounds under the PMRMA laboratory certification program. Method development and certification for NDMA and hydrazine fuel compounds in wastewater were required because either (1) suitable methods of analysis did not exist, (2) existing methods were not adequate to achieve low-level detection limits required to meet Decision Document action levels for treatment of hydrazine wastewater, or (3) existing methods did not meet the rigorous PMRMA laboratory certification criteria for method performance and reliability. This section describes development and certification of methods for analysis of NDMA and the hydrazine fuel compounds to support the full-scale startup testing program. Method development and certification were conducted in accordance with the PMRMA Chemical Quality Assurance Program, Version 1.0, 1989.

5.1 ANALYSIS OF NDMA IN WATER

EPA-approved methods for analysis of NDMA in aqueous samples include EPA Methods 607, 625, and 1625. Because the action level for NDMA identified by the Decision Document is to approach 0.0014 μg/l, none of these EPA methods was adequate to demonstrate treatment efficiency to meet the action level.

Potentially applicable analytical work on the analysis of ultra-low levels of NDMA was reported by B.J. Jody (1983) and others from IITRI. In his paper, *Ozonation of Hydrazine Fuels and Their Associated Impurities*, Jody reported that a low-level analysis was achievable for NDMA by a GC/nitrogen phosphorus detection (GC/NPD) system. The IITRI method was essentially a modified EPA Method 607.

The Army contacted IITRI and requested that they conduct method certification of the IITRI method in accordance with the PMRMA laboratory certification program. The PMRMA laboratory certification program requires a contract laboratory to demonstrate the ability to

perform the method of analysis for a specific analyte(s) using standard methods or newly developed methods and in the process generate data to be used in establishing a CRL for each analyte. The PMRMA laboratory certification program involves a two-step process, precertification and certification.

The first step, precertification, is used to evaluate instrument sensitivity and linearity over a proposed testing range of analyte concentrations. Precertification requires preparation of two separate sets of calibration standards at concentrations that bracket the testing range. The calibration standards are prepared and analyzed instrumentally in duplicate. IITRI conducted the precertification step using its modified EPA method for analysis of NDMA. IITRI's precertification analytical results were found to satisfy all linearity and instrument sensitivity requirements.

During the second step of method certification, four consecutive days of instrument calibration and spiked-sample extraction and analysis are performed and subjected to statistical analysis. The calibration range established during precertification is used for instrument calibration and spiked sample extraction and analysis. During IITRI's attempt to conduct this certification step, percent recovery values of NDMA in the spiked sample extraction analyses were found unacceptable and failed to meet PMRMA laboratory certification criteria. Based on these results, it was determined IITRI was unable to certify the method. Subsequently, the Army contracted with DataChem Laboratories (DataChem) for the development of an alternate sample extraction procedure to analyze for NDMA.

DataChem, Salt Lake City, Utah, previously completed certification for the analyses of NDMA under the PMRMA laboratory certification program at a CRL of 0.200 μg/l. DataChem's method was a modification of EPA Method 607. Because the ITTRI method could not be certified, DataChem was requested to conduct certification of its method to achieve a lower CRL than previously certified. Precertification was conducted by DataChem for the analysis of NDMA using instrument conditions similar to those used by IITRI. Precertification data generated by DataChem were found comparable to those collected by IITRI and met instrument sensitivity and linearity requirements.

Based on these results, DataChem proceeded with the second step of method certification. In an attempt to improve spiked sample recovery results conducted during the four consecutive days of instrument calibration and spiked sample extraction and analysis, the florisil column cleanup step was eliminated from the extraction procedure utilized in the previously certified DataChem NDMA method because it drastically reduced NDMA extraction efficiency. Separatory funnel extraction, used in EPA Method 607, was substituted for the florisil cleanup step and was combined with liquid-liquid continuous extraction at a pH between 5 and 9 to improve extraction efficiency.

Using this extraction step modification, four days of instrument calibration and spiked-sample extraction and analysis using the DataChem method were conducted. However, the method was found nonlinear for the high concentrations of the range tested. Accordingly, the low-level concentration range was evaluated to develop a CRL for NDMA. This evaluation resulted in a statistically determined CRL for NDMA of 0.042 μg/l.

5.2 ANALYSIS OF HYDRAZINE FUEL COMPOUNDS IN WATER

The hydrazine fuel compounds are not included among the EPA-designated priority pollutants, and an EPA-approved procedure for the analysis of hydrazine fuel compounds in water is not currently available. The most applicable method identified for analyzing hydrazine fuel compounds in water was developed by Engineering-Science (ES, 1988) for the Facilities Management Division (ASD/PMDA), Headquarters Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. In this experimental method, derivatization of the hydrazine fuel compounds using 2-furaldehyde, benzaldehyde, 2,4-pentanedione, methylethyl ketone, and cinnamaldehyde was evaluated. The reaction of the target compounds with 2-furaldehyde produced the most successful derivatization.

Based on ES's published results, VISTA Laboratories, Wheat Ridge, Colorado, was contracted to evaluate the ES method and to conduct method development and certification for hydrazine fuel compounds under the PMRMA laboratory certification program to meet the IRA

objectives of obtaining a CRL of 2.5 μg/l for hydrazine, 20 μg/l for MMH, and 25 μg/l for UDMH.

Method certification began with the reaction of 2-furaldehyde (furfural) with the hydrazine fuel compounds to create hydrazone derivatives that would be of sufficient molecular weight to extract and of sufficient stability to chromatograph. Because ethyl acetate had been used in some of the existing methods, it was decided to evaluate it as an extraction solvent. Recoveries of the hydrazone derivatives using ethyl acetate ranged from 65 to 100 percent for hydrazine, 45 to 75 percent for UDMH, and 2 to 10 percent for MMH. The 2-furaldehyde derivative of MMH yielded such a low recovery it was decided to use another derivatizing agent for this compound. A method using 2,4-pentanedione to derivatize MMH was evaluated with success.

In the initial attempts to precertify methods of analyses for hydrazine, MMH, and UDMH, poor chromatography due to an interference from the extraction solvent, ethyl acetate, was observed. In an attempt to correct this condition and to maintain consistent methods for analyses of all three hydrazine fuel compounds, a different extraction solvent was evaluated. Diethyl ether was selected as an alternative extraction solvent because of its similar polarity to ethyl acetate and because it did not degrade chromatographic performance.

Diethyl ether was found to be a suitable extraction solvent for all three hydrazine fuel compounds. Precertification was again attempted and proved successful for all three hydrazine fuel compounds.

After precertification, certification of the methods and development of CRLs for the three hydrazine fuel compounds was conducted. Certification was successful for MMH, yielding a CRL of 7.5 μg/l, which is below the IRA action level of 20 μg/l. The certification attempt for hydrazine yielded a CRL of 9.9 μg/l, which did not meet the action level of 2.5 μg/l. The certification attempt for UDMH resulted in certification as a qualitative method at the action level of 25 μg/l, which meets the IRA action level of 25 μg/l.

5.3 RESULTS OF ANALYTICAL METHODS DEVELOPMENT

Methods were successfully developed and certified subsequent to completion of the full-scale startup testing program in accordance with the PMRMA laboratory certification program for NDMA, hydrazine, MMH, and UDMH. Table 5.1 indicates the CRLs achieved for each compound. The CRLs are adequate to achieve the Decision Document action level for UDMH (25 μg/l) and to exceed the Decision Document action level of 20 μg/l for MMH. A technology-based action level was established for hydrazine on the basis of analytical method development and method certification of hydrazine in wastewater at a CRL of 9.9 μg/l. A technology-based action level was established for NDMA at 5 μg/l on the basis of treatment results demonstrated in the startup testing program. The technology-based action levels established for NDMA and the hydrazine fuel compounds indicated in Table 5.1 would apply to full-scale operations.

Table 5.1: Hydrazine Analytical Program Summary

Analyte	Method Development	Method Certification	Certified Reporting Limit (µg/l)	Decision Document Action Level (µg/l)	Technology-Based Action Level (µg/l)
NDMA	Yes	Yes	0.042	TBD	5
Hydrazine	Yes	Yes	9.9	2.5	9.9
MMH	Yes	Yes	7.5	20	7.5
UDMH	Yes	Yes	25	25	25

µg/l = micrograms per liter
NDMA = n-nitrosodimethylamine
MMH = monomethyl hydrazine
UDMH = unsymmetrical dimethyl hydrazine
TBD = to be determined

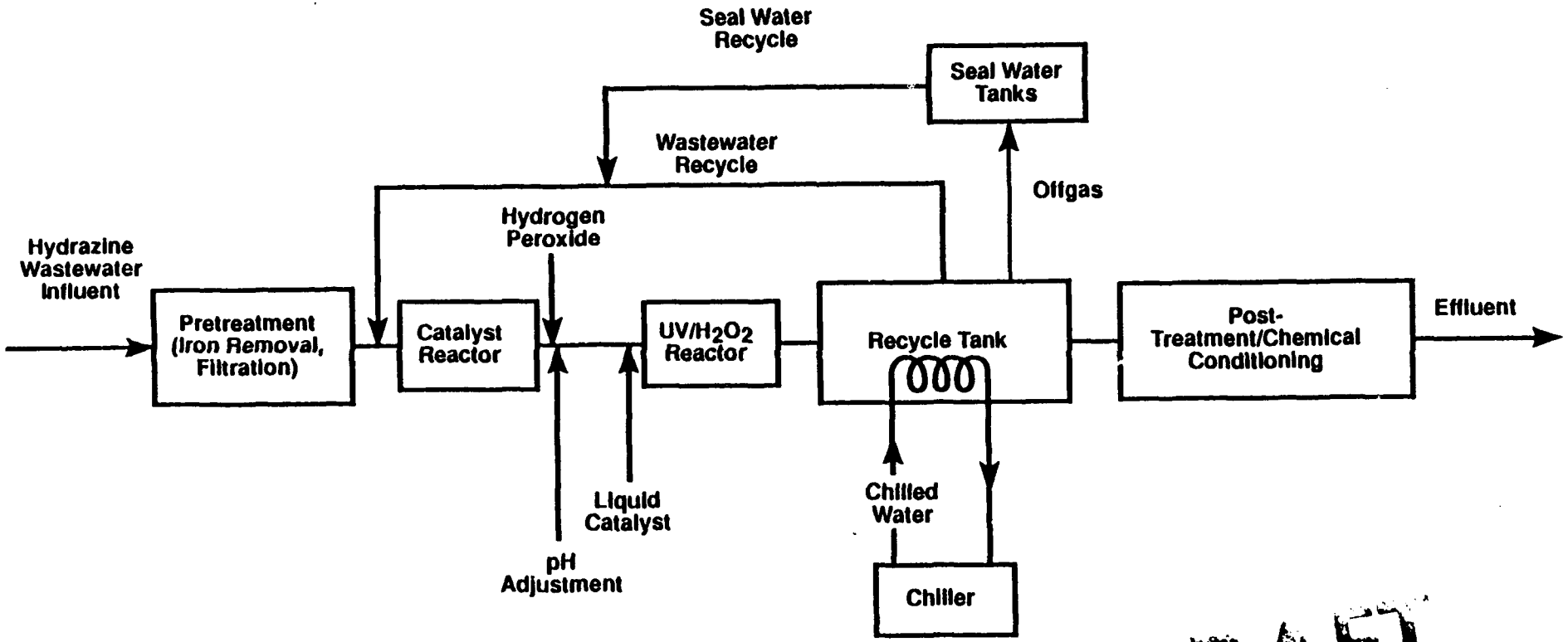
6.0 DESCRIPTION OF FULL-SCALE TREATMENT SYSTEM

From September through December, 1989, the Army constructed the hydrazine WWTF for full-scale startup operations as part of Phase I. This section describes WWTF equipment and processes used during the full-scale startup testing program. A general description of the systems used in the WWTF is presented in Section 6.1. Descriptions of the hydrazine wastewater transfer and pretreatment systems are provided in Section 6.2. A description of the flow equalization system is provided in Section 6.3. Chemical feed systems, including the hydrogen peroxide module, acid/catalyst module, and caustic module, are discussed in Section 6.4. Section 6.5 presents a discussion of the UV/chemical oxidation reactor and recycle module. Descriptions of the chiller module system, effluent storage system, and potable water distribution system are presented in Sections 6.6, 6.7, and 6.8, respectively. Sections 6.9 and 6.10 present discussions of the offgas collection system and process monitoring instrumentation/controls, respectively. The solid tungsten-rod catalyst vessel and recycle filter that were incorporated as modifications during full-scale startup testing are discussed in Section 6.11.

6.1 PROCESS DESCRIPTION

A process block diagram is shown in Figure 6.1. In general, equipment and valve numbers increase as wastewater flows through the facility and is treated. Equipment, valves, and sample taps are numbered according to the following system:

100 series	Pretreatment
200 series	UV/chemical oxidation reactor, recycle module, chemical feed pumps
300 series	Intermediate and treated effluent storage tanks, transfer pumps
400 series	Seal water system, chiller system
500 series	Potable water distribution
600 series	Chemical storage tanks



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Prepared for:
Program Manager for
Rocky Mountain Arsenal

Commerce City, Colorado

Figure 6.1

PROCESS FLOW SCHEMATIC
HYDRAZINE WASTEWATER TREATMENT FACILITY

Wastewater from tank US-4 was pumped via a submersible pump to the hydrazine WWTF through a pretreatment system and into an untreated wastewater storage tank. Process chemicals, including hydrogen peroxide, caustic, catalyst, and sulfuric acid, were introduced into the wastewater at an inlet header located upstream of the UV/chemical oxidation reactor. Mixing was accomplished by use of an in-line static mixer located downstream of the inlet header. After passing through the static mixer, wastewater passed through a catalyst pressure vessel containing tungsten rods arranged in a bundle and through a bag filter located downstream of the catalyst pressure vessel. The filter was installed to remove iron floc carry-over from the untreated wastewater storage tank.

After filtration, wastewater entered the UV/chemical oxidation reactor. Treatment was accomplished in the batch mode. A recycle module allowed continuous recirculation of wastewater through the UV/chemical oxidation reactor during treatment. The recirculated wastewater was cooled using a chiller module, which circulated coolant through cooling coils in the recycle module tank to remove excess heat generated by the treatment process. Following treatment in the UV/chemical oxidation reactor, the wastewater was pumped to one of two intermediate effluent holding tanks for sampling and pH adjustment, if necessary, before discharge to a final effluent holding tank.

More detailed descriptions of the unit processes of the treatment system are included in the following sections.

6.2 WASTEWATER TRANSFER AND PRETREATMENT

Only wastewater from tank US-4 was treated during Phase I. (Characterization of untreated hydrazine wastewater is described in Section 4.0). Transfer of wastewater from tank US-4 to the hydrazine WWTF was accomplished with a submersible wastewater transfer pump suspended in tank US-4. Untreated hydrazine wastewater entered the facility through a double-walled transfer pipeline and was routed to the pretreatment system.

For all batches treated during full-scale startup testing except batches 1 and 2, the hydrazine wastewater was pretreated to remove iron and suspended solids. Pretreatment varied among

different batches of wastewater but always included filtering the wastewater through two bag filters housed in stainless-steel units. The filters were arranged in series with the first filter capable of removing particles greater than 50 microns in diameter and the second filter capable of removing particles greater than 5 microns in diameter.

Other methods of pretreatment utilized during startup testing of batches 3 through 8 included preoxidation of the wastewater via addition of hydrogen peroxide upstream of the bag filters. Preoxidation was performed to enhance precipitation of iron. In addition, a polymer feed system was installed to provide a 2 percent weight/volume (W/V) solution of polymer to the hydrazine wastewater before transfer to the untreated wastewater storage tank T-101. The purpose of adding polymer to the hydrazine wastewater was to enhance iron floc formation and settling. An in-line static mixer was provided downstream of the polymer addition point to distribute polymer through the wastewater.

Design criteria for the transfer pump and filters were as follows:

Submersible wastewater transfer pump	
Number	1
Horsepower	3.7
Flow Capacity (Total Dynamic Head [TDH])	100 gpm (70 feet)
Type	Centrifugal, submersible
Equipment I.D.	P-101
Pretreatment filters	
Number	2
Type	Bag, polypropylene
Mode of operation	Series
Equipment I.D.	F-101, F-102

6.3 FLOW EQUALIZATION

Following pretreatment, the influent wastewater was directed to untreated wastewater holding tank T-101, which is constructed of high-density polyethylene (HDPE) and has a nominal capacity of 1100 gallons.

The purpose of the untreated wastewater holding tank was to hold untreated wastewater for a minimum of 6 hours to allow settling of iron floc. The untreated wastewater holding tank was connected to the plant water supply using chlorinated polyvinyl chloride (CPVC) pipe to pressure-

test the hydrazine WWTF process piping and to provide for system flushing. The plant water system was equipped with a backflow preventer to eliminate potential contamination of potable water. A 1-inch CPVC pipe connected the untreated wastewater holding tank to an offgas collection system. Wastewater was pumped from the untreated wastewater holding tank to the UV/chemical oxidation reactor via feed pump P-104.

Design criteria for the untreated wastewater holding tank and feed pump were as follows:

Holding tank	
Number	1
Capacity	1100 gallons
Type	Conical bottom, HDPE
Equipment I.D.	T-101
Feed pump	
Number	1
Horsepower	2.0
Flow Capacity (TDH)	50 gpm (56 feet)
Type	Centrifugal
Equipment I.D.	P-104

6.4 CHEMICAL FEED SYSTEMS

The following three chemical feed modules were used to add treatment process chemicals to the hydrazine wastewater: hydrogen peroxide module, acid/catalyst module, and caustic module. These modules are skid-mounted and consist of one or more chemical storage tanks, chemical metering and/or feed pumps, and associated control panels. Each module is also equipped with a safety shower and eyewash station designed to deliver potable water at a pressure of 40 pounds per square inch gauge (psig) for use in an emergency.

6.4.1 Hydrogen Peroxide Module

The UV/chemical oxidation treatment process utilized during startup testing at the hydrazine WWTF requires the use of hydrogen peroxide as an oxidant. Hydrogen peroxide reacts with UV light in the UV/chemical oxidation reactor to produce hydroxyl radicals that oxidize organic contaminants in the wastewater. Hydrogen peroxide was added to the influent wastewater at an inlet header located upstream of in-line mixer MX-101.

The hydrogen peroxide was stored in a 300-gallon tank as a 50 percent W/V solution. The storage tank was filled through a quick-coupler fill connection.

An 18.9-gallons-per-hour (gph) capacity manually operated feed pump and two 14-gallons-per-day (gpd) capacity manually operated metering pumps supplied hydrogen peroxide to the influent wastewater. The purpose of the hydrogen peroxide feed pump was to supply hydrogen peroxide to the influent hydrazine wastewater to achieve an initial concentration of 1000 parts per million (ppm). The hydrogen peroxide metering pumps were used to maintain this concentration during treatment. The metering pumps were connected through a common suction line and discharged to the inlet header. The feed and metering pumps were controlled from the hydrogen peroxide module control panel.

Design criteria for the hydrogen peroxide storage tank, metering pumps, and feed pump were as follows:

Hydrogen peroxide storage tank	
Number	1
Capacity	300 gallons
Type	Flat bottom, HDPE
Hydrogen peroxide metering pump	
Number	2
Capacity	14 gpd
Type	Diaphragm
Equipment I.D.	P-201B, P-201C
Hydrogen peroxide feed pump	
Number	1
Horsepower	0.04
Capacity	18.9 gph
Type	Positive displacement
Equipment I.D.	P-201A

6.4.2 Acid/Catalyst Module

Sulfuric acid (93 percent W/V) was supplied to the hydrazine wastewater at two locations for the purpose of reducing the pH of the wastewater: at the inlet header upstream of in-line static mixer MX-101, and before in-line static mixer MX-102. Catalyst (20 percent W/V) was supplied to the influent wastewater stream at the inlet header for the purpose of enhancing chemical destruction efficiency during full-scale startup testing of batches 1 and 2.

These chemicals were stored in separate 55-gallon U.S. Department of Transportation (DOT)-approved containers.

Two 18.9-gph capacity manually operated feed pumps were used to transfer sulfuric acid and catalyst from the storage containers to the waste stream. The feed pumps were controlled from the acid/catalyst module control panel.

Design criteria for the components of this module were as follows:

Catalyst storage tank	
Number	1
Capacity	55 gallons
Type	Polyethylene drum
Acid storage tank	
Number	1
Capacity	55 gallons
Type	Polyethylene drum
Catalyst feed pump	
Number	1
Horsepower	0.04
Capacity	18.9 gph
Type	Positive displacement gear
Equipment I.D.	P-202
Acid feed pump	
Number	1
Horsepower	0.04
Capacity	18.9 gph
Type	Positive displacement gear
Equipment I.D.	P-203

6.4.3 Caustic Module

When necessary, the pH of the wastewater was raised by addition of sodium hydroxide (20 percent W/V). Sodium hydroxide was stored in a 300-gallon HDPE tank located on the caustic module. A caustic injection point was provided at the inlet header upstream of MX-101 for the purpose of raising the pH of the untreated wastewater before or during treatment. An additional caustic injection point was provided upstream of MX-102 for the purpose of raising the treated wastewater pH to levels acceptable for discharge.

The caustic module contained two pairs of metering pumps: one pair for pH adjustment before and/or during treatment and one pair for pH adjustment of treated wastewater. Both sets of pumps were manually controlled from the caustic module control panel.

Design criteria for the components of this module were as follows:

Caustic storage tank	
Number	1
Capacity	300 gallons
Type	Flat bottom, HDPE
Caustic metering pumps	
Number	4
Capacity	14 gpd
Type	Diaphragm
Equipment I.D.	P-204A, P-204B, P-204C, P-204D

6.5 UV/CHEMICAL OXIDATION REACTOR AND RECYCLE MODULE

The UV/chemical oxidation reactor used for startup testing is a perox-pure™ model CW-120 manufactured by PSI. This reactor consists of an oxidation chamber, a lamp-drive enclosure, and a control panel. The oxidation chamber is a welded stainless-steel vessel that contains eight UV lamps mounted horizontally inside quartz sheaths. The UV/chemical oxidation reactor is designed to be operated at a water pressure of 15 psig. Because the chamber is not an American Society of Mechanical Engineers (ASME)-coded pressure vessel, the unit is equipped with a pressure relief system consisting of a rupture disc designed to burst at 20 psig, a flow switch for alarm and shut-down when the disc ruptures, and piping connections for conveyance of relief flow to the recycle tank. The system is skid-mounted for ease of transportation and installation.

Wastewater to be treated enters the bottom of the reactor vessel and flows upward past the UV lamps. Wastewater exits the top of the reactor and overflows to the recycle module tank (T-201). The UV/chemical oxidation system was operated in batch mode with continuous recirculation through the recycle module tank to provide cooling of the hydrazine wastewater during treatment.

The recycle module consisted of a recycle pump, control panel, and recycle module tank T-201. Tank T-201 was constructed of HDPE and has a nominal capacity of 1000 gallons. The

recycle module tank was equipped with a cooling coil. Coolant was supplied to the recycle module tank from chiller module CH-101.

As a control safety feature, the UV/chemical oxidation reactor and auxiliary equipment controls were interlocked with recycle pump P-201 and all chemical feed and metering pumps.

Design criteria for the UV/chemical oxidation reactor and recycle module were as follows:

UV/chemical oxidation reactor	
Reactor type	perox-pure™ Model CW-120
Process flow rate	Batch
Process temperature	40-140 °F
Operating pressure range	3-15 psig
Equipment I.D.	R-201
Recycle pump	
Number	1
Horsepower	3
Flow capacity (TDH)	105 gpm (55 feet)
Type	Centrifugal
Equipment I.D.	P-201
Recycle module tank	
Number	1
Capacity	1000 gallons
Type	*Flat bottom, HDPE*
Equipment I.D.	T-201

6.6 CHILLER MODULE

Wastewater treated by the UV/chemical oxidation treatment process increases in temperature as a result of chemical reactions and heat output from the UV lamps. The temperature of the wastewater must be lowered to reduce pressure buildup in the UV/chemical oxidation reactor and to prevent boiling of the wastewater. The chiller module reduced the temperature of the wastewater by circulating coolant through cooling coils in recycle module tank T-201. The chiller module controls were adjusted to prevent wastewater from exceeding 140°F during treatment.

Design criteria for the chiller module were as follows:

Chiller	
Number	1
Capacity	240,000 BTUs/hr
Type	Reciprocating liquid
Equipment I.D.	CH-401

6.7 EFFLUENT STORAGE

Two intermediate effluent holding tanks (T-301 and T-302) with a nominal capacity of 1100 gallons each were used to store treated wastewater before transfer to final effluent holding tank T-305. T-305 was provided to hold treated wastewater before PMRMA-certified characterization of the effluent and final discharge.

Design criteria for these tanks and pumps were as follows:

Intermediate effluent holding tank	
Number	2
Capacity	1100 gallons
Type	Conical bottom, HDPE
Equipment I.D.	T-301, T-302
Final effluent holding tank	
Number	1
Capacity	5000 gallons
Type	Flat bottom, HDPE
Equipment I.D.	T-305
Effluent pump	
Number	1
Horsepower	2.0
Flow capacity (TDH)	50 gpm (56 feet)
Type	Centrifugal
Equipment I.D.	P-301
Unloading pump	
Number	1
Horsepower	2.0
Flow capacity (TDH)	50 gpm (56 feet)
Type	Centrifugal
Equipment I.D.	P-305

6.8 POTABLE WATER DISTRIBUTION SYSTEM

Potable water from the RMA potable water distribution system enters the hydrazine WWTF through a 1-1/4-inch CPVC pipe and is routed to a skid-mounted water-pressure booster system. The purpose of the water-pressure booster system is to provide the capability to supply potable water at a constant pressure within the hydrazine WWTF. The water-pressure booster consists of a 200-gallon pressure tank (T-501) and a centrifugal water booster pump (P-501).

Design criteria for the components of this system were as follows:

Water booster pump	
Number	1
Horsepower	5
Flow Capacity (TDH)	50 gpm (110 feet)
Type	Centrifugal
Equipment I.D.	P-501
Pressure tank	
Number	1
Capacity	200 gallons
Type	ASME bag type
Equipment I.D.	Expansion tank T-501

6.9 OFFGAS COLLECTION SYSTEM

The purpose of the offgas collection system was to collect potentially contaminated offgas from tanks T-201, T-301, T-302, and T-305 and to disperse the gas through water for scrubbing. The system consisted of two vertical polyethylene seal-water tanks (T-401 and T-402) with a nominal capacity of 300 gallons each and 1-inch CPVC piping for diverting offgas to the seal-water tanks.

Potentially contaminated offgas was dispersed through potable water that was placed in the seal-water tanks for that purpose. In addition, two vapor-phase granular activated carbon (GAC) filters were connected in series to the only outlet of the seal water system. The purpose of the GAC filters was to capture organic contaminants that were not removed by the seal water system. A centrifugal seal-water pump was provided to transfer wastewater generated from offgas treatment to tank T-101 for future treatment.

Design criteria for the tanks and pump were as follows:

Seal water tanks	
Number	2
Type	Polyethylene
Capacity	300 gallons
Equipment I.D.	T-401, T-402
Seal water pump	
Number	1
Horsepower	3
Capacity (flow) (TDH)	105 gpm (55 feet)
Type	Centrifugal
Equipment I.D.	P-402

6.10 PROCESS MONITORING INSTRUMENTATION AND CONTROLS

Process monitoring instrumentation was provided to monitor process conditions, including pH, temperature, pressure, flow rate, oxidation/reduction potential (ORP), and UV intensity.

The pH sensors were provided downstream of MX-101 and downstream of MX-102 to monitor the pH before, during, and after treatment.

Temperature indicators were provided to monitor the temperature of the hydrazine wastewater entering and exiting the UV/chemical oxidation reactor and to monitor the temperature of the coolant entering and exiting the recycle module tank. The temperature indicators were passive instruments with no control function.

Pressure gauges were provided to monitor UV/chemical oxidation reactor pressure and to monitor pressure on the discharge side of pumps P-104, P-201, P-201B, P-201C, P-202, P-203, P-204A, P-204B, P-204C, P-204D, P-301, P-401, P-402, and P-501. The pressure gauges were passive instruments with no control function. In addition, two pressure gauges were provided to monitor pressure drop across the bag filter units to determine the need for bag replacement. A passive pressure-vacuum indicator was provided to monitor positive or negative pressure in offgas collection piping that resulted from filling or draining tanks T-101, T-301, and T-302.

A flow sensor provided signal output to the flow meter/totalizer in the UV/chemical oxidation reactor control panel (CP-201). The flow sensor was used to monitor flow entering the UV/chemical oxidation reactor. The total volume of wastewater treated was calculated for a particular batch using readings from the flow totalizer. These readings provided an indication of total reaction time afforded each batch.

An ORP sensor and signal output monitor provided continuous readings of the ORP in the hydrazine wastewater during treatment. ORP was monitored to ensure that adequate oxidizing conditions existed during treatment.

The intensity of UV light in the UV/chemical oxidation reactor was periodically monitored by a UV intensity sensor installed in the reactor wall. The sensor provided signal output to a UV intensity monitor located on the top of the UV/chemical oxidation reactor. UV intensity was

monitored to evaluate whether the quartz tubes surrounding the UV lamps were free of accumulation.

6.11 CATALYST VESSEL AND RECYCLE FILTER

A catalyst vessel and bag filter were added between the reactor and recycle tank as treatment system modifications during full-scale startup testing. The catalyst vessel was added to determine the effect of tungsten on treatment performance.

A bag filter housed in a stainless-steel unit was added to remove iron floc that may have carried over from feed tank T-101.

Design criteria for the catalyst vessel and filter were as follows:

Catalyst vessel	
Number	1
Type	Stainless-steel
Equipment I.D.	Not applicable
Recycle filter	
Number	1
Type	Bag, polypropylene
Equipment I.D.	Not applicable

7.0 FULL-SCALE STARTUP TESTING PROGRAM

From January through May, 1990, a total of 9920 gallons of hydrazine wastewater from tank US-4 was treated during full-scale startup testing at the WWTF. Wastewater from tank US-4 was used because it contained the highest concentrations of the hydrazine fuel compounds of the three storage tanks (Table 4.1). The UV/chemical oxidation treatment system was operated in batch mode with an average of 1100 gallons treated per each of nine batches.

Operating parameters for each batch were based on previous experiments summarized in Sections 2.1 and 2.2, bench-scale testing performed by PSI, and treatment of previous batches of hydrazine wastewater during full-scale startup testing. The sampling and analytical programs, general and specific operating procedures for each batch, and results of the full-scale startup testing program follow.

7.1 SAMPLING AND ANALYTICAL PROGRAMS

Sampling and analytical programs were developed to characterize influent, process effluent (during treatment), and final effluent wastewater; ambient air; and treatment operations offgas during the full-scale startup testing program. The following sections discuss sample types, sampling frequency, analytical parameters, and methods of analyses used to characterize each medium. Also discussed is the quality assurance/quality control QA/QC program developed to evaluate the technical utility of analytical results obtained during the full-scale startup testing program.

7.1.1 Wastewater Sampling Program

To evaluate the efficiency of the full-scale UV/chemical oxidation system during startup testing, influent and final effluent samples were collected from each of the nine batches treated, with the exception of batch 2 for which the influent concentration was assumed to be equivalent to that for batch 1. Process effluent samples were collected for batches 3, 4, 5, and 9 to construct chemical characterization curves to evaluate process performance versus time. Process effluent samples for batches 3, 4, 5, and 9 were collected at either two-hour or four-hour intervals during

treatment of each batch. Batch 3 was run for a cumulative treatment time of 100 hours. During the first 50 hours, process effluent samples were collected every two hours. After an additional 50 hours of treatment, a final effluent sample was collected. Batch 4 was run for a cumulative treatment time of 46 hours. Process effluent samples were collected every four hours for the first 34 hours of treatment operation, and a final effluent sample was collected at hour 46. Process effluent samples were not collected between hours 34 and 46 of treatment operation for batch 4. Batch 5 was run for a cumulative treatment time of 34 hours. Samples were collected at two-hour intervals for the first 12 hours of treatment. Process effluent samples were then collected after 24, 26, and 30 hours of treatment operation. No samples were collected between 12 and 24 hours of treatment operation. A final effluent sample was collected at hour 34 of treatment operation for batch 5. Batch 9 was run for a cumulative treatment time of 53 hours. Process effluent samples were collected at two-hour intervals for the first 46 hours of treatment operation. A final effluent sample was collected after 53 hours of treatment operation for batch 9.

During batch 3, 27 process effluent samples were collected for chemical analysis. During batch 4, 13 process effluent samples were collected. For batches 5 and 9, a total of 11 and 25 process effluent samples, respectively, were collected.

7.1.2 Wastewater Analytical Program

During full-scale startup testing, all influent and final effluent samples were analyzed for the following parameters:

- Hydrazine fuel compounds (hydrazine, MMH, and UDMH)
- NDMA
- Priority pollutant VOCs

All process effluent samples were analyzed for hydrazine fuel compounds and NDMA. Process effluent samples collected immediately after pH adjustments were also analyzed for priority pollutant VOCs. Influent and final effluent samples collected from batch 1 were analyzed for priority pollutant VOCs, priority pollutant SVOCs, priority pollutant pesticides, nitrogen-

phosphorus pesticides, organosulfur compounds, phosphonates (i.e., DIMP and DMMP), and priority pollutant metals. Priority pollutant VOCs, priority pollutant SVOCs, and priority pollutant pesticide analyses were analyzed by EPA Methods 8240, 8270, and 8080, respectively. Nitrogen-phosphorus pesticides, organosulfur compounds, and phosphonates were analyzed using PMRMA-certified methods. Priority pollutant metals were analyzed using the appropriate EPA 300-series methods. A summary of the analyses performed on samples from each treated batch is presented in Table 7.1.

During the period between completion of the bench/pilot-scale testing program and initiation of full-scale startup testing, efforts were continued to improve performance and reliability of the methods developed for analysis of NDMA and the hydrazine fuel compounds in wastewater. As a result of these efforts, improvements were made that included increased reliability of the MRLs established during the bench/pilot-scale testing program. However, when full-scale startup testing was conducted, methods certification for NDMA and the hydrazine fuel compounds had not been completed, and CRLs had not been established for these compounds. Consequently, influent, process, and effluent samples collected during the full-scale startup testing program were analyzed by noncertified methods. Because the MRLs established for NDMA and hydrazine fuel compounds utilizing the newly developed methods were considered more reliable than the MDLs and attained the lowest technologically achievable reporting limits, these methods were considered adequate to monitor full-scale startup testing performance and evaluate treatment efficiency to meet technology-based action levels.

7.1.3 QA/QC Program

A QA/QC program was developed to assure the precision, accuracy, representativeness, and comparability of analytical results generated to evaluate the performance of the UV/chemical oxidation treatment system. Two types of QC samples were collected in an attempt to assure the technical utility of analytical results: (1) external or field QC samples and (2) internal or laboratory QC samples. External QC samples were used to evaluate the precision of analytical results and the effects of sampling procedures on the representativeness of results. Internal QC

Table 7.1: Full-Scale Startup Testing Analytical Program

Analytical Parameter(s)	Batch 1		Batch 2		Batch 3			Batch 4			Batch 5			Batch 6		Batch 7		Batch 8		Batch 9		
	I	E	I	E	I	P	E	I	P	E	I	P	E	I	E	I	E	I	E	I	P	E
Hydrazine fuel compounds	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NDMA	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Priority pollutant volatile organic compounds	x	x			x	x	x	x	x	x	x			x	x	x	x			x		x
Priority pollutant semivolatile organic compounds	x	x																				
Priority pollutant pesticides	x	x																				
Nitrogen-phosphorus pesticides	x	x																				
Organosulfur compounds	x	x																				
Phosphonates	x	x																				
Priority pollutant metals (and iron)	x	x																				
2,3,7,8-Tetrachlorodibenzo-p-dioxin	x																					

I = influent samples
E = effluent samples
P = process samples
x = analysis conducted for indicated analytical parameter(s)
NDMA = n-nitrosodimethylamine

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samples were used to evaluate the accuracy of the laboratory analyses and to estimate the influence of laboratory sample preparation on the representativeness of the reported analytical results. In addition, QA audits of randomly selected analytical data packages were conducted quarterly during the program to assure the completeness and accuracy of the analytical results. Data generated during the program were processed through the PMRMA Installation Restoration Data Management System (IRDMS) to assure data were generated in accordance with the PMRMA-approved analytical method protocols.

7.1.3.1 Field QA/QC

External or field QC samples were collected periodically during sampling to evaluate the effects of sampling on the representativeness of analytical results. Trip blanks of ultra-pure organic-free water were used when high- and low-level concentration wastewater samples had to be shipped together in the same shipment container. Trip blanks were used to evaluate the possible influence of contaminant crossover from high-level concentration samples to low-level concentration samples during shipment and sample storage at the laboratory.

Field blanks consisted of samples of ultra-pure organic-free water that were transported to the HBSF in sample containers and placed upwind of the influent and effluent wastewater sampling locations with the container cap removed. Field blanks were used to evaluate the possible influence of target compounds present in ambient air on investigative sample results.

Rinse blanks consisted of ultra-pure organic-free water poured through air from one pre-cleaned container to another at the time of influent and effluent wastewater sampling. Rinse blanks were used to evaluate the possible influence of target compounds present in WWTF air on investigative sample results. The results of the external QC sample investigation are discussed in Section 7.3.5.

7.1.3.2 Laboratory QA/QC

Laboratory QA/QC protocol employed for the Phase I analytical program was consistent with protocol employed for PMRMA and EPA programs. Internal QC sample types required by these methods included a method blank analyzed with each sample analytical lot. A multipoint calibration and a continuing calibration were run to assure the accuracy of quantitative results. In addition, matrix spike and matrix spike duplicate (MS/MSD) samples were analyzed to monitor system performance and to evaluate matrix effects of the hydrazine wastewater on reported analytical results.

The laboratory protocol for analysis of NDMA included five separate extraction blank studies used to isolate observed carryover problems due to high-level concentration NDMA samples. Details of the effect of internal QC sample results on related investigative samples are presented in Section 7.3.5.

7.1.4 Air Monitoring

The air-monitoring program conducted during startup testing at the WWTF consisted of several methods, both real-time and nonreal-time, for evaluating facility air concentrations of hydrazine, MMH, UDMH, NDMA, and VOCs. This program was conducted to evaluate (1) the integrity of the UV/chemical oxidation treatment system and (2) the potential exposures to personnel during wastewater treatment and facility maintenance activities. The results of the air-monitoring program are discussed in Section 7.3.4.

7.1.4.1 Exposure Limits

The following Permissible Exposure Limits (PELs) as established by OSHA were adopted as ARARs in the final Decision Document:

Substance	Exposure Limit
Hydrazine	8-hour TWA: 0.1 ppm (skin)
NDMA*	No Permissible Contact Level
Methylene chloride	8-hour TWA: 500 ppm
Chloroform	CL: 50 ppm
1,1-dichloroethane	8-hour TWA: 200 ppm
1,1-dichloroethylene	8-hour TWA: 5 ppm

* = NDMA is regulated as a suspected human carcinogen in 29 CFR 1910.1016
TWA = time weighted average
CL = ceiling limit

In addition to the OSHA PELs in the final Decision Document, the following PELs were utilized in this IRA (OSHA, 1990).

Substance	PEL
MMH	8-hour TWA: 200 ppb (ceiling concentration)
UDMH	8-hour TWA: 500 ppb

7.1.4.2 Air Modeling

To evaluate the implications of a release of wastewater at the WWTF and subsequent dispersion of NDMA away from the WWTF, a single-release air-modeling program, TRPUF, was used. Two different release scenarios were considered: (1) a worst-case release and (2) an average case. Analytical results from samples obtained during startup testing treatment of Batch 1 indicate that NDMA concentrations in wastewater may be as high as 8000 μg/l during the initial hours of treatment. The worst-case air modeling scenario considered a release within the secondary containment system in the WWTF during the initial hours of treatment of 1000 gallons of wastewater containing 8000 μg/l of NDMA.

The average case evaluated represented the release of untreated wastewater from holding tank T-101. Wastewater pumped from US-4 is held in tank T-101 within the facility before treatment. The concentration of NDMA in the untreated wastewater before startup testing treatment of batch 3 was 280 μg/l. The average-case scenario considered a failure of tank T-101 releasing 1000 gallons of untreated wastewater containing 300 μg/l of NDMA. The conservative assumption that all NDMA was immediately volatilized, completely mixed with the air within the WWTF, and exhausted through the exhaust fan located on the roof of the WWTF was employed for the average-case scenario.

The TRPUF model was run for the two scenarios, using the Slade dispersion coefficients, building downwash algorithm, and meteorological data from Denver Stapleton International Airport. Because the TRPUF model evaluates a single instantaneous release, the location of the downwind maximum concentrations of NDMA are dependent on the prevailing wind direction at the time of release. One-hour average concentrations were obtained for distances of 80 feet and 10,000 feet from the WWTF. Because of building downwash effects, concentrations reported in the model at distances of less than 80 feet are unreliable. A distance of 10,000 feet represents the distance to the southern boundary of RMA, the closest boundary to the WWTF.

Results of the air modeling evaluation indicate that for the average release scenario, the maximum 60 minute average NDMA concentrations were 0.59 $\mu g/m^3$ at 80 feet and 0.03 $\mu g/m^3$ at 10,000 feet. For the worst-case release scenario, the maximum 60 minute average NDMA concentrations were 0.39 $\mu g/m^3$ at 80 feet and 1.37 $\mu g/m^3$ at 10,000 feet. Based on conservative risk assessment calculations using the Risk Assessment Guidance for Superfund (EPA, 1989), the lifetime excess cancer risk associated with the exposure scenarios ranges from 9×10^{-14} to 2×10^{-10}. Therefore, the risk is acceptable.

7.1.4.3 Nonreal-Time Air-Monitoring Program

ThermoSorb-N cartridges specific for nitrosamines and ThermoSorb-A cartridges specific for hydrazine fuel compounds were used to monitor for the presence of NDMA and hydrazine fuel compounds during various phases of the full-scale startup testing program. Cartridges used during this portion of the air-monitoring program were supplied by Thermedics, Inc., in Woburn, Massachusetts. The ThermoSorb-N cartridges contain an artifact trap to prevent the nitrosification of airborne amine compounds, which could result in false positives. These cartridges were connected to a personal air monitoring pump calibrated to an air flow of 2.0 liters per minute and placed at various locations within the facility during full-scale startup testing. After a sampling time of approximately 8 hours, the cartridges were returned to Thermedics, Inc., for analysis.

7.1.4.4 Real-Time Air Monitoring Program

Two TLD-1 toxic gas detectors manufactured by MDA Scientific, Inc., Lincolnshire, Illinois, one located above the UV/chemical oxidation reactor and the other located between seal-water tanks T-401 and T-402, were connected to strip chart recorders to provide a continuous record, updated in 15-minute increments, of hydrazine fuel compound concentrations in the ambient air of the WWTF. The detector located above the UV/chemical oxidation reactor was calibrated for hydrazine. The second detector was calibrated for either MMH or UDMH. MMH and UDMH were not detected in the untreated wastewater at concentrations as high as that of hydrazine. A dedicated monitor for UDMH and MMH was therefore not considered necessary. The lowest PEL for the hydrazine fuel compounds is the one established for hydrazine, and the ratio of the air concentrations of MMH and UDMH to hydrazine was anticipated to be constant, based on a similar rate of destruction during the treatment process. Monitoring for (1) MMH over UDMH or (2) UDMH over MMH was performed periodically at the discretion of the sampler. The instrument detection limits for these compounds using the MDA Scientific, Inc., instruments are 5 ppb for hydrazine, 10 ppb for MMH, and 25 ppb for UDMH. Audible and visual alarms were set in the WWTF at the PEL for each compound (i.e., 100 ppb for hydrazine and 200 ppb for MMH or 500 ppm for UDMH).

7.1.4.5 Hydrazine Detection Badges and Hydrazine Colorimetric Tubes

Chemically reactive paper hydrazine detection badges purchased from Lab Safety Supply, Janesville, Wisconsin, were used as an additional method to evaluate both personnel exposures to hydrazine and air concentrations of hydrazine within the WWTF. According to the manufacturer, these badges change color from white to yellow after 15 minutes of exposure to hydrazine concentrations above the PEL (100 ppb).

These badges were also placed at six locations throughout the WWTF at locations considered to be potential sources of fugitive hydrazine emissions. These locations were as follows:

1. Valve 001 - Initial valve allowing untreated wastewater into filters F-101 and F-102
2. Valve 007 - Valve allowing untreated wastewater and chemical additives into reactor

3. Valve 009 - Valve allowing treated wastewater into intermediate effluent holding tanks T-301 and T-302 via pump P-201
4. Pressure relief device (vacuum breaker) on untreated wastewater storage tank T-101
5. Pressure relief device (vacuum breaker) on intermediate effluent holding tank T-301
6. Pressure relief device (vacuum breaker) on intermediate effluent holding tank T-302

Direct-reading hydrazine detector tubes manufactured by Sensidyne, Inc., Largo, Florida, were also used periodically during startup testing to monitor hydrazine concentrations in the air inside the WWTF. Locations for monitoring varied depending on the operations performed but most often were near the UV/chemical oxidation reactor and the recycle pump. This method draws a measured volume of air through a chemically-reactive sorbent tube. The presence and concentration of hydrazine are indicated by a color change from pink to yellow and the length of stain, respectively. These tubes have an accuracy tolerance of 25 percent at one, two, and five times the PEL and 35 percent at one-half the PEL.

7.1.4.6 Photoionization Monitoring for VOCs

Because VOCs were previously reported in the untreated hydrazine wastewater, routine monitoring for VOCs within the WWTF during startup testing was conducted using a photoionization detector (PID). Although the PID is not equally sensitive to all VOCs reported in the wastewater and chemical-specific concentrations would not be available, routine monitoring would provide a general assessment of the concentrations of VOCs (and other photoionizable compounds, if present) in the air within the WWTF.

7.1.5 Operating Parameters

Operating parameters were used to evaluate treatment process performance with respect to destruction rates and overall removal of hydrazine fuel compounds and NDMA from the wastewater. The following parameters were monitored during treatment by UV/chemical oxidation:

- pH - The pH was monitored during each batch by collecting a 500-ml sample every hour and measuring with an Orion SA250 meter.

- ORP - Readings of ORP were recorded every hour from a Signet ORP meter located at the inlet to the reactor.

- UV intensity - UV transmission through the wastewater was measured every hour with an International Light radiometer/photometer that included an optical sensor located in the lower one-half of the rear sidewall of the reactor.

- Temperature - Temperature was recorded to measure the temperature rise across the reactor. Temperature was also monitored as a safety measure to ensure the reactor operating temperature would not exceed 140° F. Readings were recorded every hour from temperature gauges located in the inlet and outlet of the reactor.

- Oxidant concentration - Hydrogen peroxide concentrations were measured every hour using EM Quant® brand test strips, which indicate hydrogen peroxide concentration colorimetrically.

7.2 OPERATING PROCEDURES

7.2.1 General Operating Procedures

Operating procedures common to all of the batches are discussed below.

Before treatment in the UV/chemical oxidation reactor, each batch of wastewater was pumped from tank US-4 to untreated wastewater holding tank T-101 located within the WWTF. Bag filtration pretreatment was accomplished for each batch during the transfer operation, as described in Section 6.2. From the untreated wastewater holding tank, the filtered wastewater was pumped to the UV/chemical oxidation reactor/recycle tank system. During each batch, wastewater was pumped from the recycle tank through the UV/chemical oxidation reactor and back into the recycle tank. In the reactor, the wastewater was exposed to UV radiation at a wavelength of 245 nm and a maximum intensity in the reactor of 134,400 watts.

The temperature of the wastewater in the reactor/recycle tank system was maintained below 140° F through the use of cooling coils in the recycle tank and a chiller. Treatment chemicals were added in the pipeline that connects the outlet of the reactor to the recycle tank inlet. Treatment chemicals included hydrogen peroxide for oxidation, ferrous sulfate as a catalyst (batch 1 only), and sulfuric acid or sodium hydroxide for pH adjustment.

Hydrogen peroxide concentration, operating temperature, ORP, recycle rate, UV intensity, cumulative time treated, and pH were monitored and recorded during treatment of each batch.

7.2.2 Specific Operating Procedures for Each Batch

Several operating parameters were varied during treatment of each batch to develop the recommended scenario for treatment of the wastewater during Phase II. A discussion of these variations follows, and a summary of the operating parameters that were recorded during treatment of each batch is included in Table 7.2.

Operating conditions for the initial batch (batch 1) were established on the basis of recommendations of PSI from its bench-scale testing. Those recommendations were to maintain (1) pH of the wastewater solution between 3 and 5, (2) hydrogen peroxide concentration of 1000 mg/l, and (3) ferrous sulfate catalyst concentration of 5 mg/l. The bench-scale testing indicated that under these operating conditions the hydrazine fuel compounds and NDMA concentrations should be reduced to less than MRLs in approximately 16 hours. During treatment of the initial batch, pH was adjusted to 2.7 and maintained below 6.0.

Although the hydrazine fuel compounds were reduced to less than MRLs at the end of batch 1, NDMA concentration in the treated wastewater was greater than the MRL. Therefore, batch 1 was retreated twice in an attempt to reduce the treated wastewater NDMA concentration to below the MRL. Iron fouling of the quartz sheaths that surround the UV bulbs occurred during batch 1. Iron fouling results in decreased UV irradiation of the wastewater. Also, an iron concentration of greater than 7 mg/l was measured in the untreated wastewater before batch 1 treatment. Therefore, it was decided to eliminate the use of ferrous sulfate catalyst during batch 2.

The pH of the untreated wastewater before batch 2 treatment was 9.3. After approximately 6.5 hours, the pH was lowered to and maintained at less than 4.0. No ferrous sulfate catalyst was added during batch 2, but approximately 15 mg/l of total iron was measured using Merckoquant® iron test strips. Iron fouling of the quartz sheaths also occurred during treatment of this batch.

Because of the high iron concentrations measured in the untreated wastewater and the iron fouling concern, three modifications were incorporated in the treatment system for use in subsequent batches: (1) an iron removal pretreatment system for the untreated wastewater was

Table 7.2: *Summary of Treatment Operating Parameters*

Parameter	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8	Batch 9
pH range (units)	5.9 to 2.5	4.1 to 2.0	8.7 to 1.3	8.9 to 2.1	1.7 to 1.4	1.8 to 1.4	1.5 to 1.3	9.3 to 1.4	9 to 1.2
Catalyst	Ferrous sulfate solution	None	Tungsten rods	Tungsten rods	Tungsten rods	Tungsten rods	Tungsten rods	Tungsten rods	Tungsten rods
Cumulative treatment time for batch (hours)	33	60	50	46	34	52	69	34	53
Total volume treated (gallons)	720	1300	1300	1300	1300	1000	1000	1000	1000
Recycle rate range (gpm)	65 from 147	65 from 151	76 from 134	68 from 76	74 from 82	84 from 86	NF	NF	80 from 82
ORP range (mv)	+301 to +684	-138 to +692	-43 to +667	-303 to +625	+506 to +660	+504 to +658	-54 to +648	-300 to +633	-87 to +669
Maximum operating temperature (°F)	130	122	136	130	130	122	127	142	141
H_2O_2 concentration range (mg/l)	300 to 1000	600 to 2500	250 to 2500	500 to 2500	50 to 2500	500 to 4500	100 to 2500	50 to 4000	200 to 10,000

°F = degrees Fahrenheit
gpm = gallons per minute
mv = millivolts
mg/l = milligrams per liter
NF = not functioning
ORP = oxidation-reduction potential
H_2O_2 = hydrogen peroxide

installed, (2) a bag filter was placed in the pipeline between the reactor and the recycle tank, and (3) a tungsten rod catalyst reactor was installed in the pipeline between the reactor and the recycle tank to replace the ferrous sulfate catalyst system. The iron removal pretreatment system included hydrogen peroxide addition for oxidation of iron to the ferric state, polymer addition to aid in settling of iron floc, an in-line static mixer, and settling of iron floc for a minimum of four hours in the untreated wastewater holding tank before transfer of the pretreated wastewater to the UV/chemical oxidation reactor/recycle tank system.

Hydrogen peroxide and an anionic polymer (Betz 1125L) were added to the untreated wastewater at doses of 5 mg/l and 2 mg/l, respectively, for batches 3 through 8. Use of the iron removal pretreatment system was discontinued during batch 9 because the iron oxidation step was found to also cause oxidation of UDMH to NDMA before treatment in the UV/chemical oxidation reactor.

The in-line bag filter and catalyst reactor modifications were used in batches 3 through 9.

Batch 3 was treated at an initial pH of 8.7. During treatment, the pH of the wastewater decreased and eventually stabilized at a pH of approximately 7.6. After stabilization, the pH was lowered to less than 2.0 for the duration of treatment. The pH of batch 4 was adjusted twice during treatment. The pH decreased from an initial value of 9.0 to a stable value of 7.0. After stabilization, the pH was adjusted to 4.2. After several hours of treatment at this pH, the pH of the wastewater was lowered to 2.2 for the duration of treatment. The pH of the wastewater during treatment of batches 5, 6, and 7 was lowered to less than 2.0 and maintained at this pH throughout treatment. The initial pH of batches 8 and 9 was 9.6 and 9.2, respectively. After stabilization of pH in the range of 7.0 to 7.8, the pH was lowered to less than 2.0 for the remainder of treatment of these batches.

During batches 5, 6, 7, 8, and 9 the hydrogen peroxide concentration was increased to a level above 2000 mg/l after pH adjustment to acidic conditions. This treatment variation was performed to evaluate the effect of increased hydrogen peroxide concentration on NDMA destruction rates.

7.3 TREATMENT RESULTS/DISCUSSION

Full-scale startup testing was conducted to evaluate (1) applicability of bench/pilot-scale testing results with respect to full-scale operating parameters, (2) whether treatment goals set forth by the Decision Document could be obtained by the UV/chemical oxidation process, and (3) the optimum set of operating conditions for destruction of hydrazine fuel compounds and NDMA in the wastewater utilizing the UV/chemical oxidation treatment process.

Nine batches of wastewater from tank US-4 were treated by the UV/chemical oxidation process. As discussed in Section 7.1, process effluent samples were collected at either two- or four-hour intervals to construct chemical characterization curves to evaluate process performance versus time for batches 3, 4, 5, and 9. The results from these batches were used to evaluate whether treatment goals were achieved and to provide the basis for full-scale operating procedures to be used in Phase II. The remaining batches were sampled at the beginning and end of their treatment cycles and were not used to evaluate performance or provide recommendations for full-scale operation.

Operating parameters were also used to evaluate treatment process performance with respect to removal of hydrazine fuel compounds and NDMA from the wastewater. The parameters of pH, ORP, and hydrogen peroxide concentration were the most important measurable factors in determining treatment process performance.

Results from the full-scale startup testing program are presented in the following sections and include discussions of operating parameters, operational results, corrosion, air monitoring, and analytical QA/QC.

7.3.1 Operating Parameters

Batch 3 was the first batch for which chemical characterization curves were developed. This batch was pretreated for iron removal. The pH of the wastewater was not adjusted until 30 hours into the treatment cycle. During the initial 30 hours of treatment, the pH was allowed to fluctuate as the photochemical reaction dictated. Upon stabilization at 7.3, the pH was adjusted by manually adding sulfuric acid until a pH of 1.4 was obtained. Treatment continued until a reactor

shutdown occurred at hour 86 due to high reactor temperature. This shutdown lasted for 4 hours and 30 minutes. Hydrogen peroxide concentration was adjusted during treatment of the batch to maintain an average concentration of between 1000 and 1500 mg/l.

The second chemically characterized batch was batch 4. This batch was also pretreated for iron removal. The initial pH of the wastewater was not altered until hour 15. During this time, the pH was allowed to fluctuate as the photochemical reaction dictated. Upon stabilization at a pH of 7.0, the pH was adjusted by manually adding sulfuric acid until the pH value of 4.2 was obtained. This procedure was performed a second time at hour 23 when the pH was adjusted from 5.3 to 3.7. Hydrogen peroxide concentration was adjusted during this batch to maintain an average concentration between 1000 and 1500 mg/l. No equipment operational difficulties occurred during batch 4.

The third chemically characterized batch was batch 5. This batch was also pretreated for iron removal. The pH of the untreated wastewater was lowered by the manual addition of sulfuric acid until a pH value of 1.7 was reached. The pH was then allowed to fluctuate as the photochemical reaction dictated. The hydrogen peroxide concentration was maintained between 750 and 2500 mg/l. The hydrogen peroxide concentration dropped to a low value of 50 mg/l sometime overnight when the facility was unattended. The hydrogen peroxide chemical metering pump feed setting appeared to be set too low for the hydrogen peroxide demand during this time period. No equipment operational difficulties occurred during batch 5.

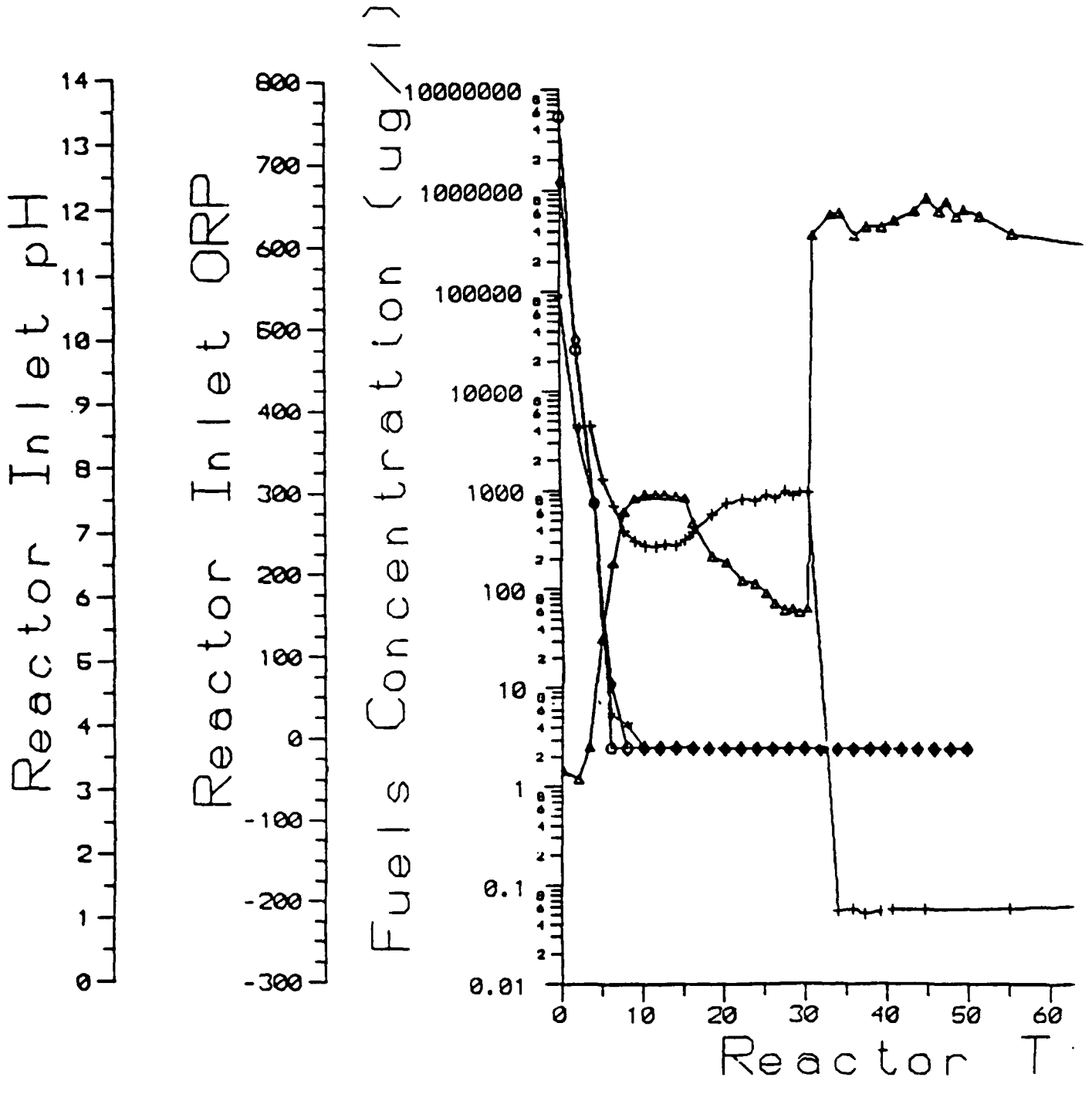
The final chemically characterized batch was batch 9. The pH of the untreated wastewater was adjusted from an initial value of 6.6 to 9.3 using sodium hydroxide. This pH adjustment was performed during the first 30 minutes of the treatment cycle. Iron was removed during this run by mechanical filtration only. The pH for this batch was allowed to fluctuate as the photochemical reaction dictated. Upon stabilization of the pH at a value of 7.7 at hour 17, the pH was adjusted manually by adding sulfuric acid until a pH of 1.8 was obtained. Four mechanical shutdowns occurred during treatment of batch 9 due to excessive reactor temperature. The reactor shutdowns at hours 20 and 27 created a downtime of 1 hour and 5 hours, respectively.

The other two reactor shutdowns lasted for less than 30 minutes each. The hydrogen peroxide concentration was maintained at an average concentration of between 1000 and 1500 mg/l before pH adjustment to 1.8. After pH adjustment, the hydrogen peroxide concentration in the wastewater was allowed to reach a maximum value of 10,000 mg/l and allowed to decrease to a nondetectable level at the end of the treatment cycle.

7.3.2 Discussion of Operational Results

Reactor inlet pH, reactor inlet ORP, and the concentration of hydrazine fuel compounds and NDMA as a function of time for batch 3 are shown in Figures 7.1 and 7.2. The initial pH of the untreated wastewater was 8.6. After 10 hours of treatment, the pH had fallen to near neutral. The ORP during this time period increased from a -30 millivolt (mv) reducing environment to a +310 mv oxidizing environment. During this time period, the hydrazine fuel compounds were either reduced to below MRLs or converted to other products. The concentration of NDMA in this batch increased during the initial hours of treatment. This increase is assumed to be due to the fact that NDMA is a degradation byproduct of UDMH. NDMA was reduced to a level of below 5 μg/l after 31 hours of treatment and was not detected at a level in excess of 0.5 μg/l for the duration of the treatment cycle.

The curves depicting concentrations of hydrazine fuel compounds as a function of time for batch 4 were similar to batch 3 except the rate of destruction was approximately two times slower than in batch 3. This is shown in Figure 7.3. After 17 hours of treatment, the wastewater pH decreased to a near neutral value and the hydrazine fuel compounds appeared to be reduced to or below the action levels for those compounds specified in the Decision Document. ORP, after 17 hours of treatment, was measured at +450 mv (oxidizing environment), which indicated a significant increase from the initial ORP value of -300 mv (reducing environment). Figure 7.4 indicates that after 24 hours, the NDMA in batch 4 was reduced to a level of less than 5 μg/l. NDMA concentration continued to decrease with treatment time. Upon completion of batch 4, the NDMA concentration was measured at 52 ppt.



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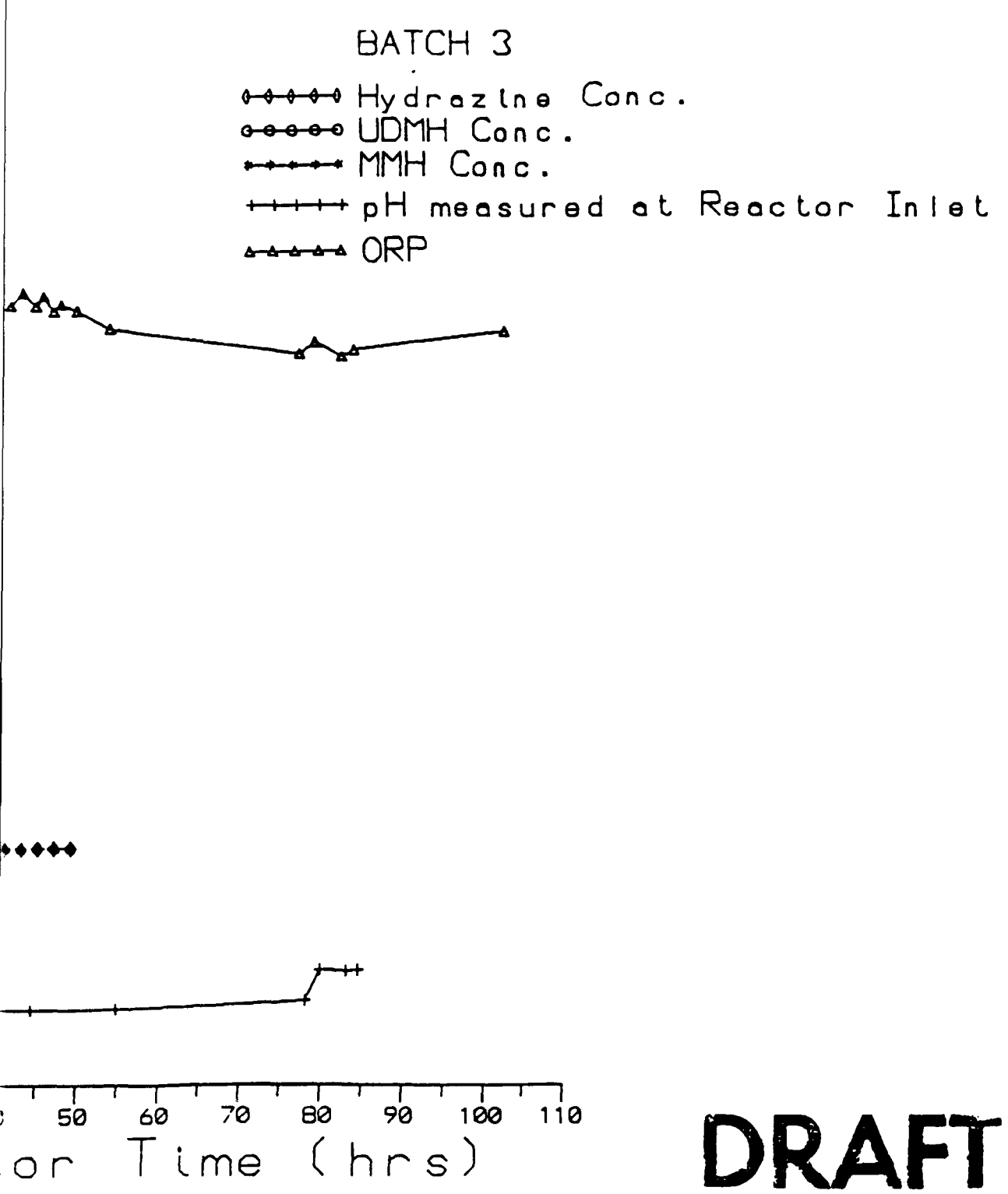

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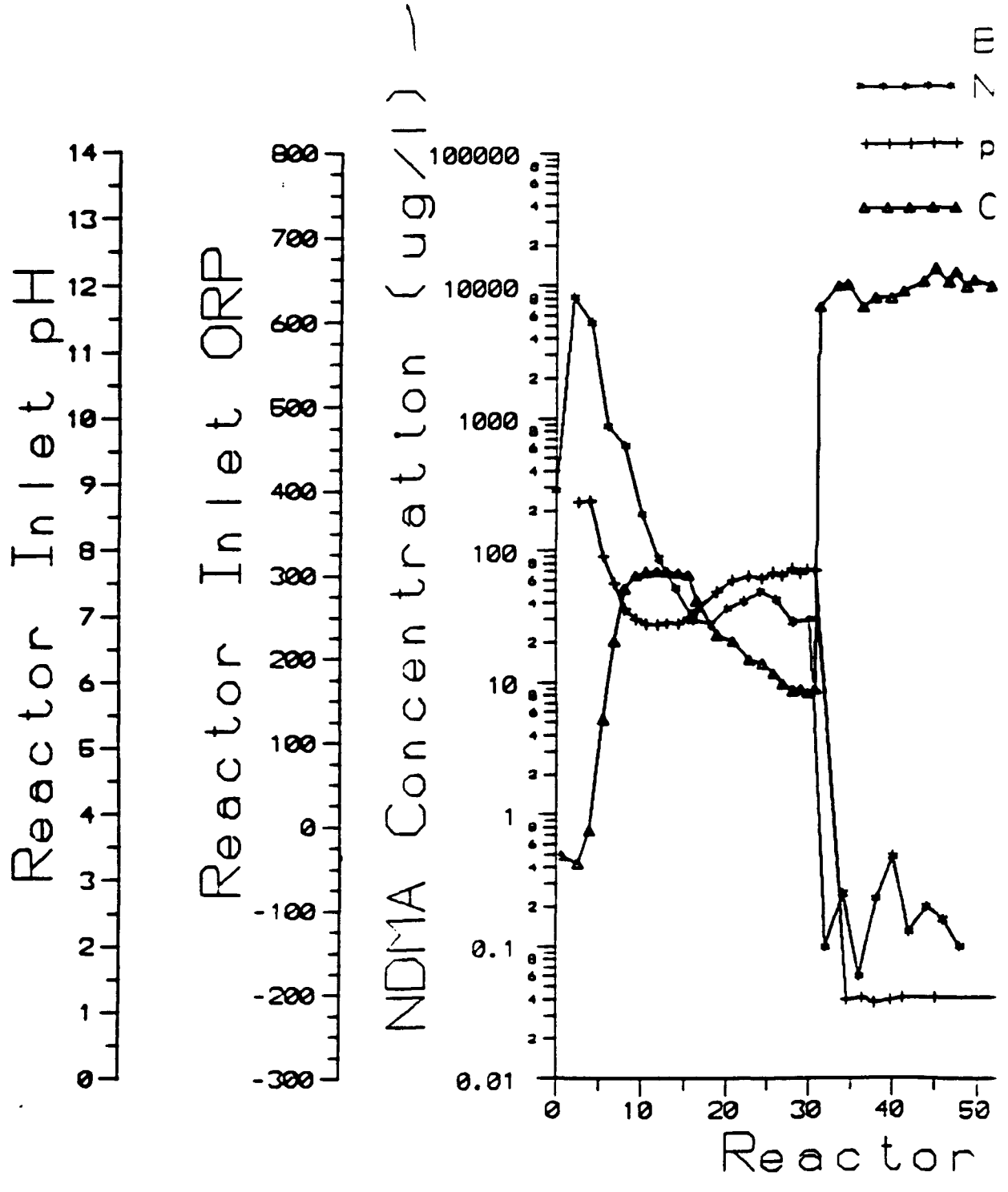
Figure 7.1
REACTOR INLET pH, REACTOR INLET ORP, AND HYDRAZINE FUEL COMPOUNDS CONCENTRATIONS VS. REACTOR TIME - BATCH 3



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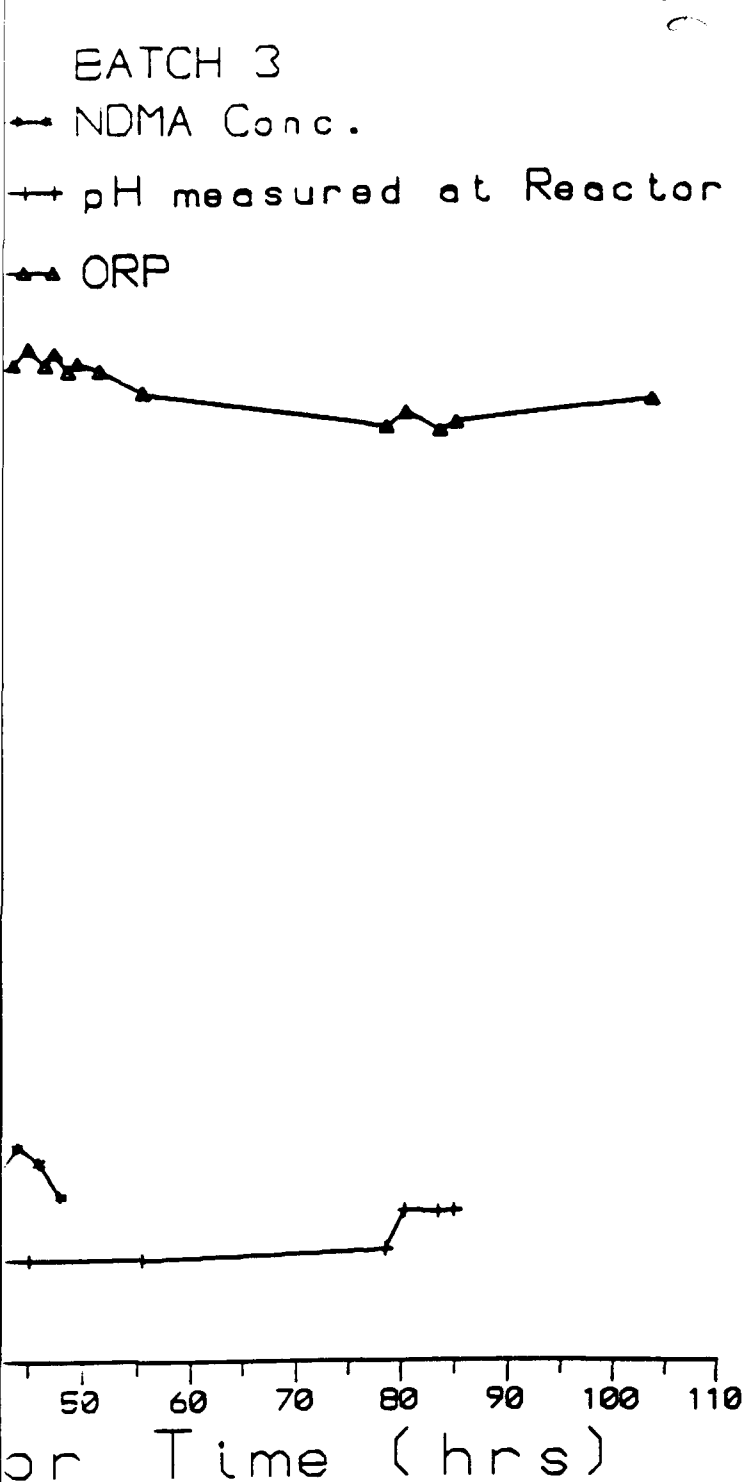

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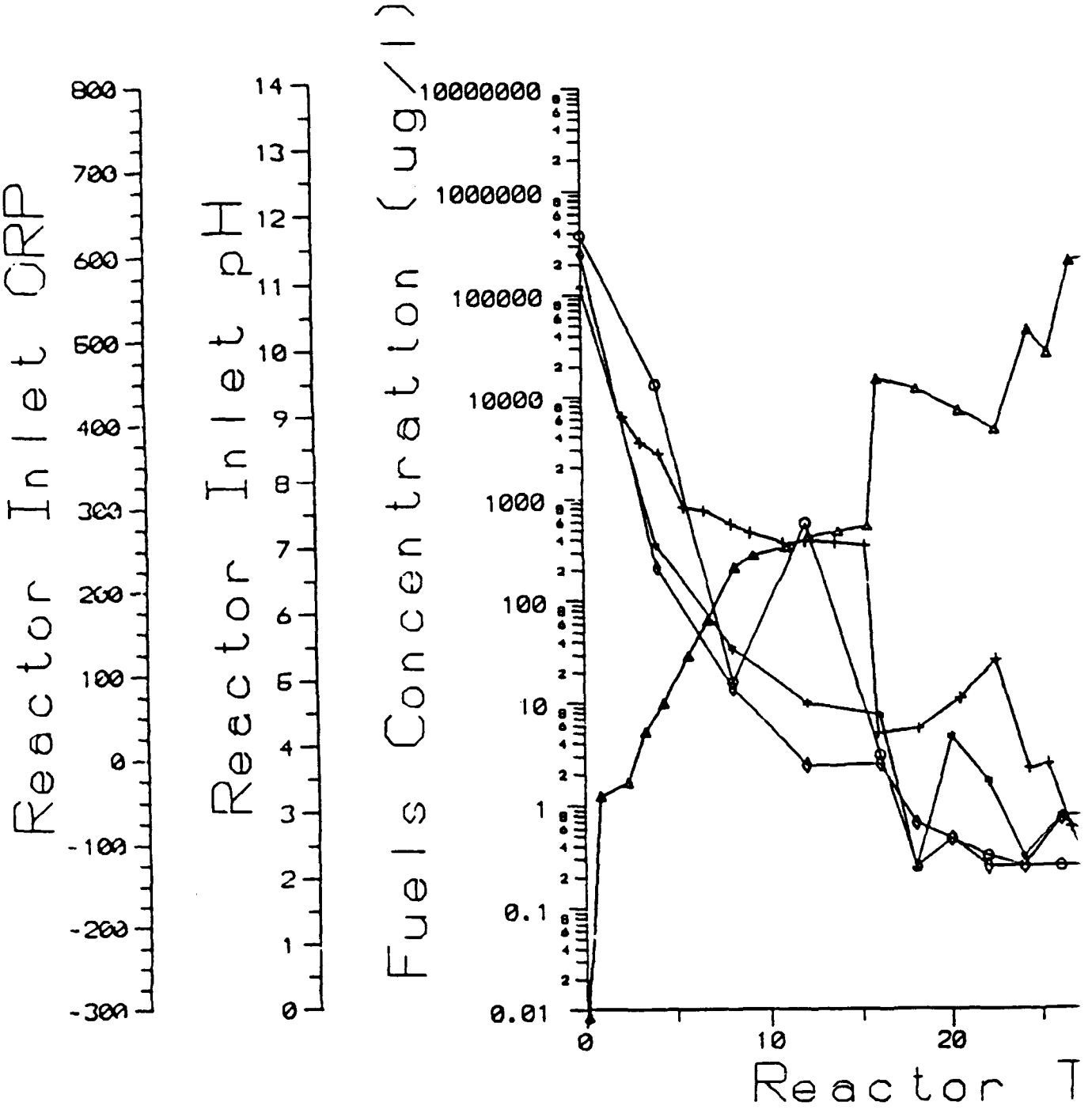
Figure 7.2
REACTOR INLET pH, REACTOR INLET ORP, AND NDMA CONCENTRATION VS. REACTOR TIME – BATCH 3



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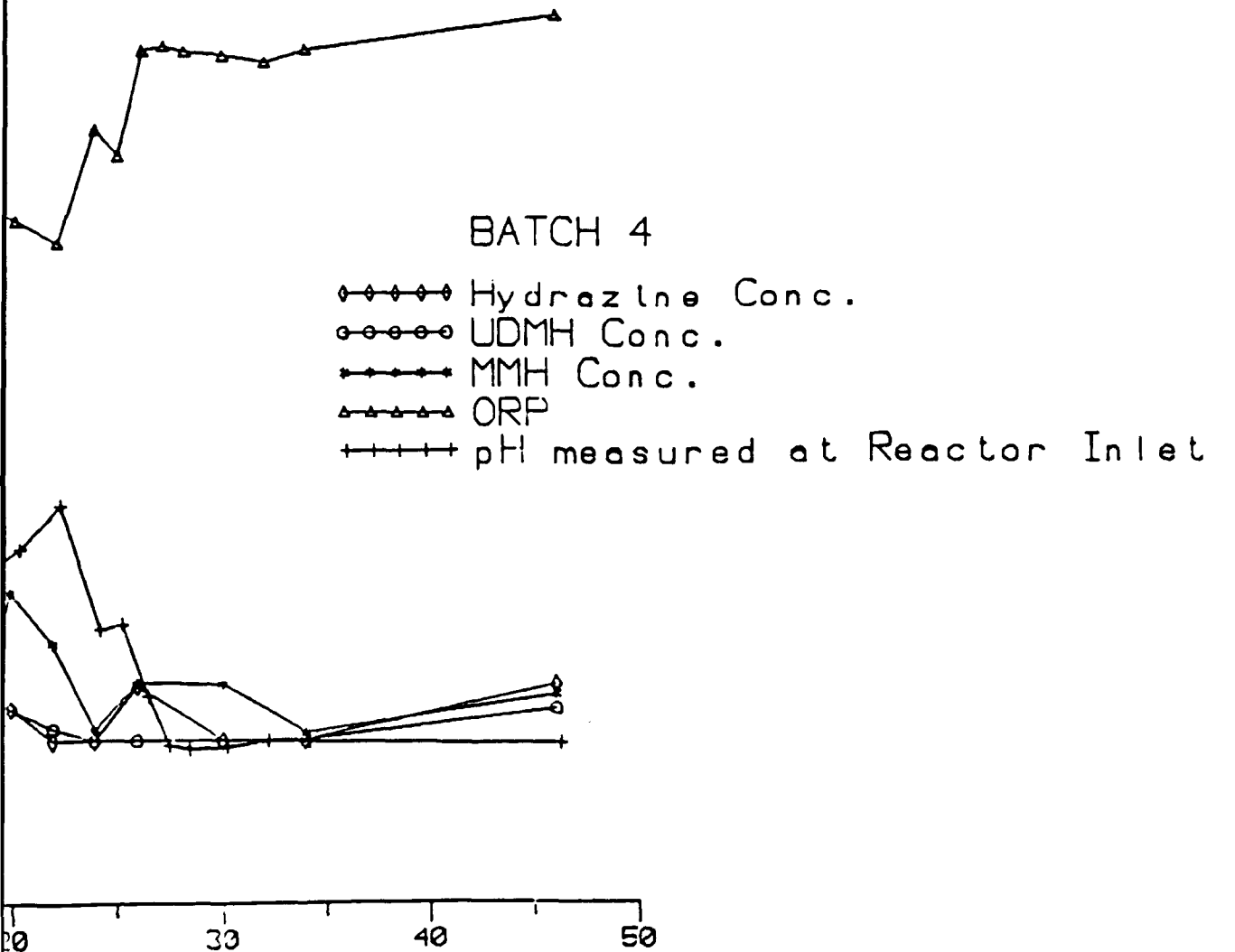
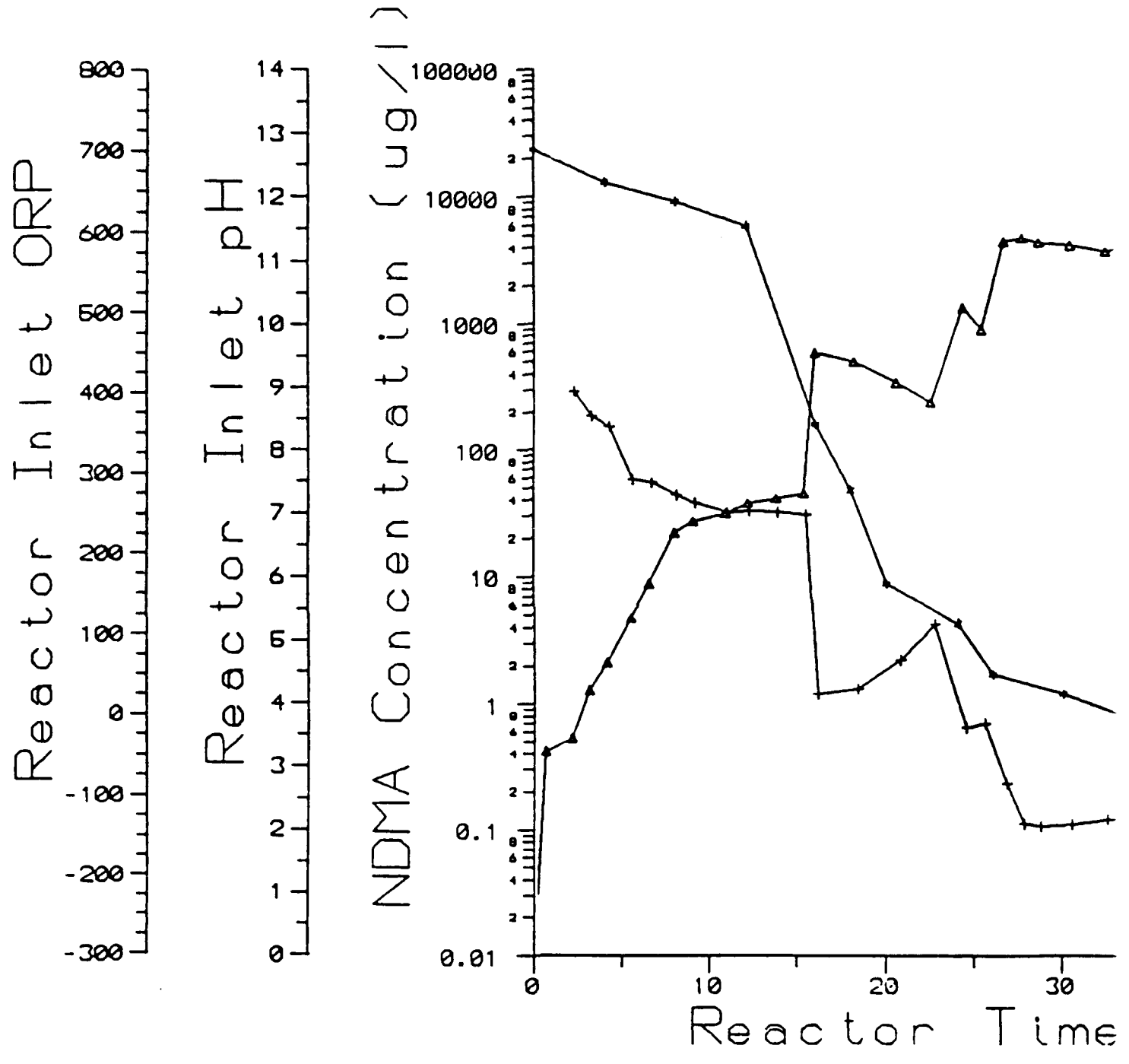


Figure 7.3
REACTOR INLET pH, REACTOR INLET ORP, AND HYDRAZINE FUEL COMPOUNDS CONCENTRATIONS VS. REACTOR TIME - BATCH 4



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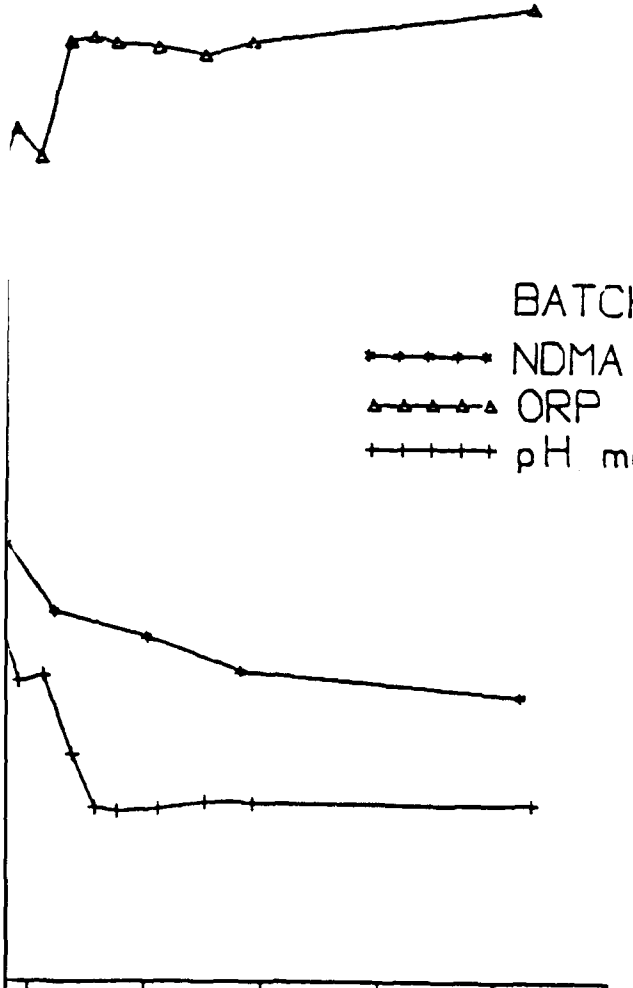
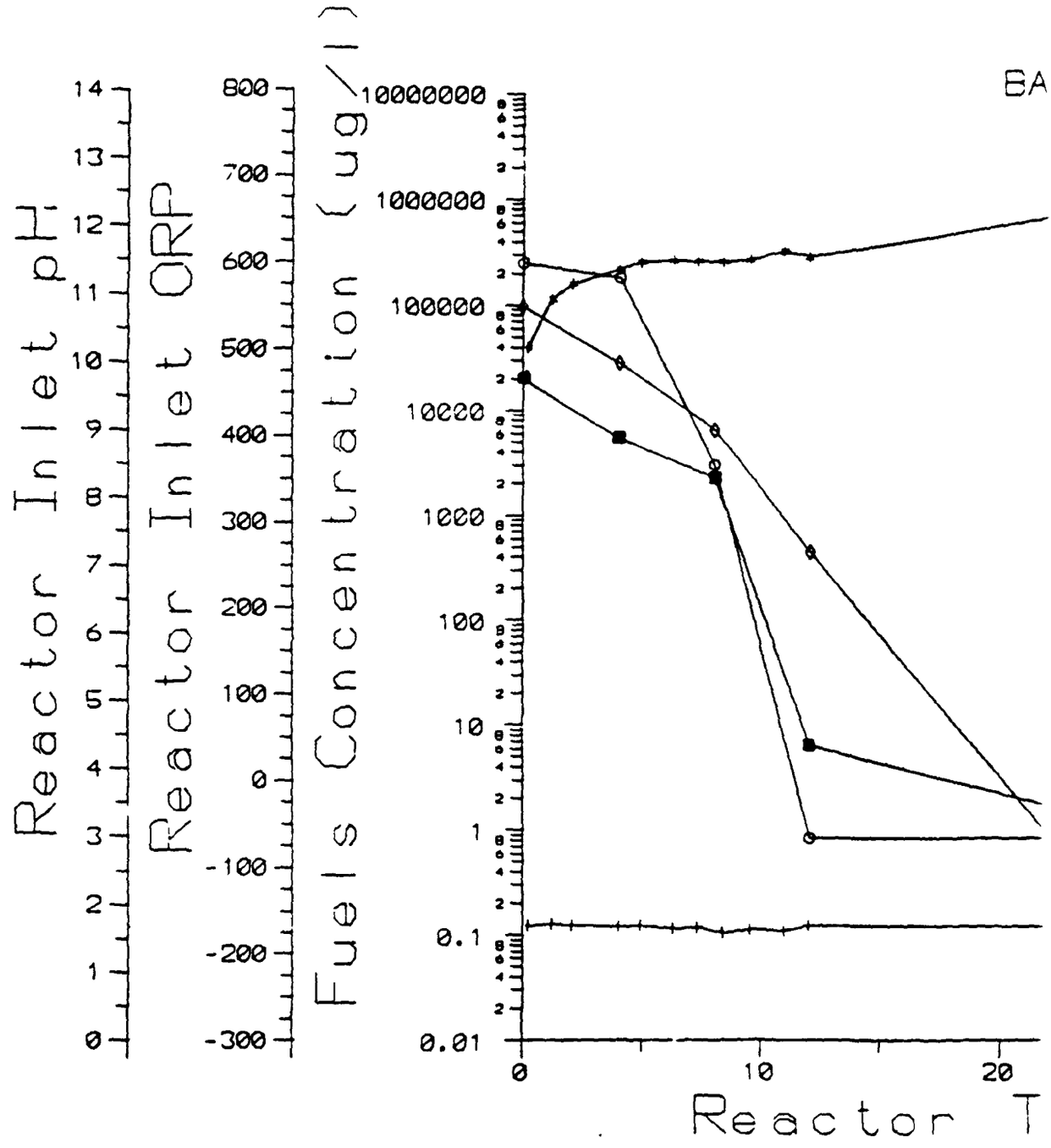


Figure 7.4
REACTOR INLET pH, REACTOR INLET ORP, AND NDMA CONCENTRATION VS. REACTOR TIME – BATCH 4

As indicated in Figure 7.5, the curves depicting concentration of hydrazine fuel compounds as a function of time for batch 5 were similar to those observed for batch 3. After 32 hours of treatment, the hydrazine fuel compounds were reduced to MRLs. The destruction rates for the hydrazine fuel compounds were significantly slower in batch 5 than those observed in batches 3 and 4. This appears to be due to the adjustment to acidic pH conditions (pH of 1.67) at the start of the run. The initial pH of the influent for batches 3 and 4 was very basic. Hydrazine in a basic solution is known to be more reactive than hydrazine in an acidic solution. This increase in the reactivity for hydrazine is shown by the destruction rates for the hydrazine fuel compounds for this batch. As shown in Figure 7.6, NDMA in batch 5 was successfully treated to below 5 μg/l in 19 hours. The ORP for batch 5 was in excess of +500 mv throughout the run. The NDMA concentration reached a low of 0.72 μg/l in 24 hours of treatment time. However, the NDMA did increase in concentration to 150 μg/l at 34 hours. This increase in NDMA corresponded to an increase in hydrogen peroxide concentration of 50 mg/l at 24 hours and 2500 mg/l at 36 hours. Similar increases in NDMA concentration with time were recorded by WES in batches treated with high hydrogen peroxide concentrations (WES, 1989).

The destruction rates resulting from treatment of hydrazine fuel compounds during batch 9 were similar to those observed for batch 3. This is shown in Figure 7.7, which is a plot of reactor inlet pH, reactor inlet ORP, and the concentration of hydrazine fuel compounds versus time. In batch 9, it appears that the concentration of MMH in the untreated wastewater may have influenced the initial kinetics relative to MMH destruction. After 17 hours of treatment, the hydrazine fuel compounds were reduced to MRLs. At this time, an ORP of +225 mv and a near neutral pH were measured. As indicated in Figure 7.8, the concentration of NDMA in this batch was reduced to 5 μg/l after only 10 hours of treatment. With further treatment, the NDMA concentration did increase to a maximum of 9 μg/l at approximately 32 hours of treatment. Similar increases in NDMA concentrations were also observed by WES in batches treated with high hydrogen peroxide concentrations (WES, 1989). The NDMA concentration also dropped to below 5 μg/l after eight hours of additional treatment and remained below 5 μg/l for the duration



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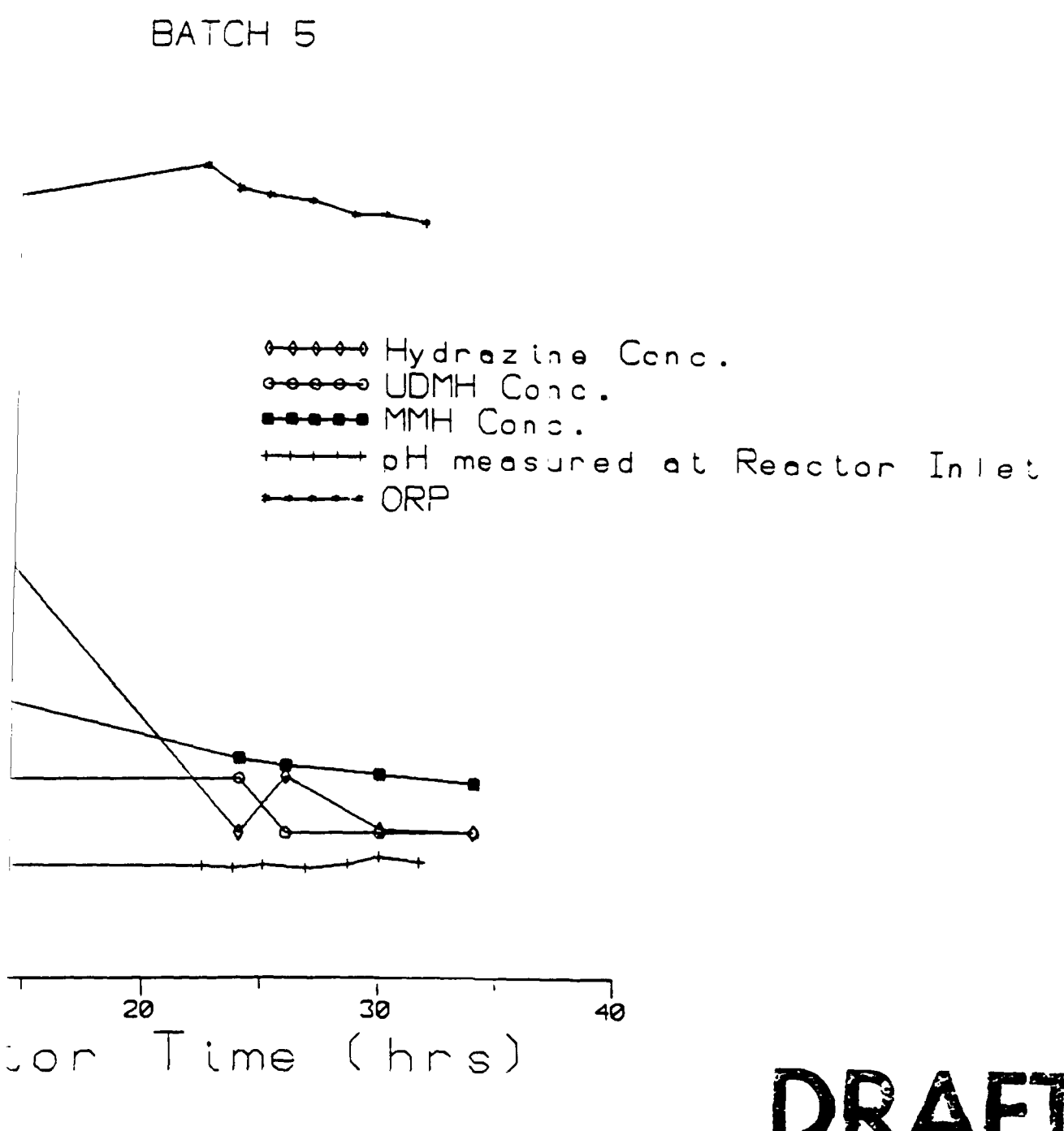

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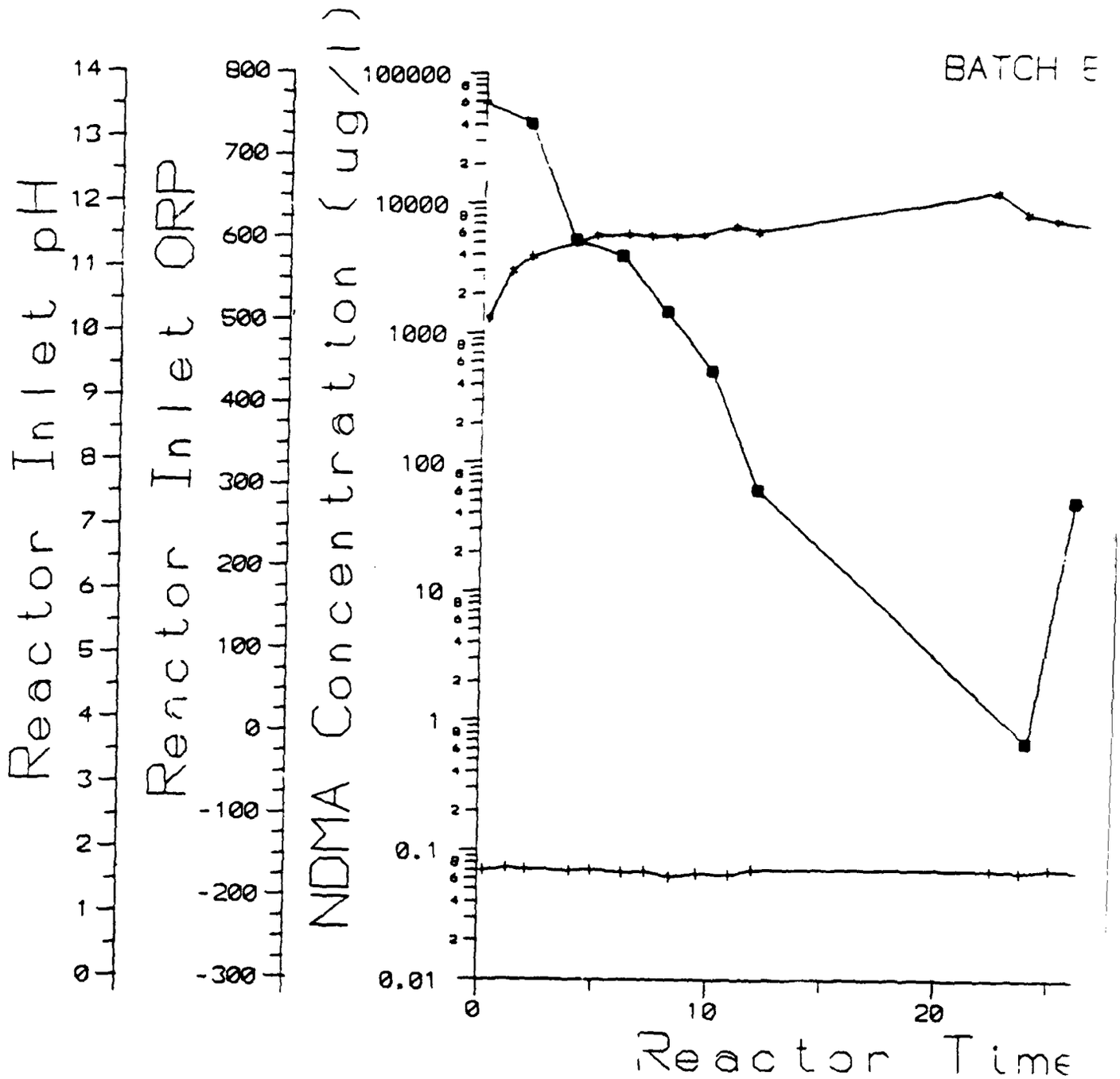
Figure 7.5
REACTOR INLET pH, REACTOR INLET ORP, AND HYDRAZINE FUEL COMPOUNDS CONCENTRATIONS VS. REACTOR TIME - BATCH 5



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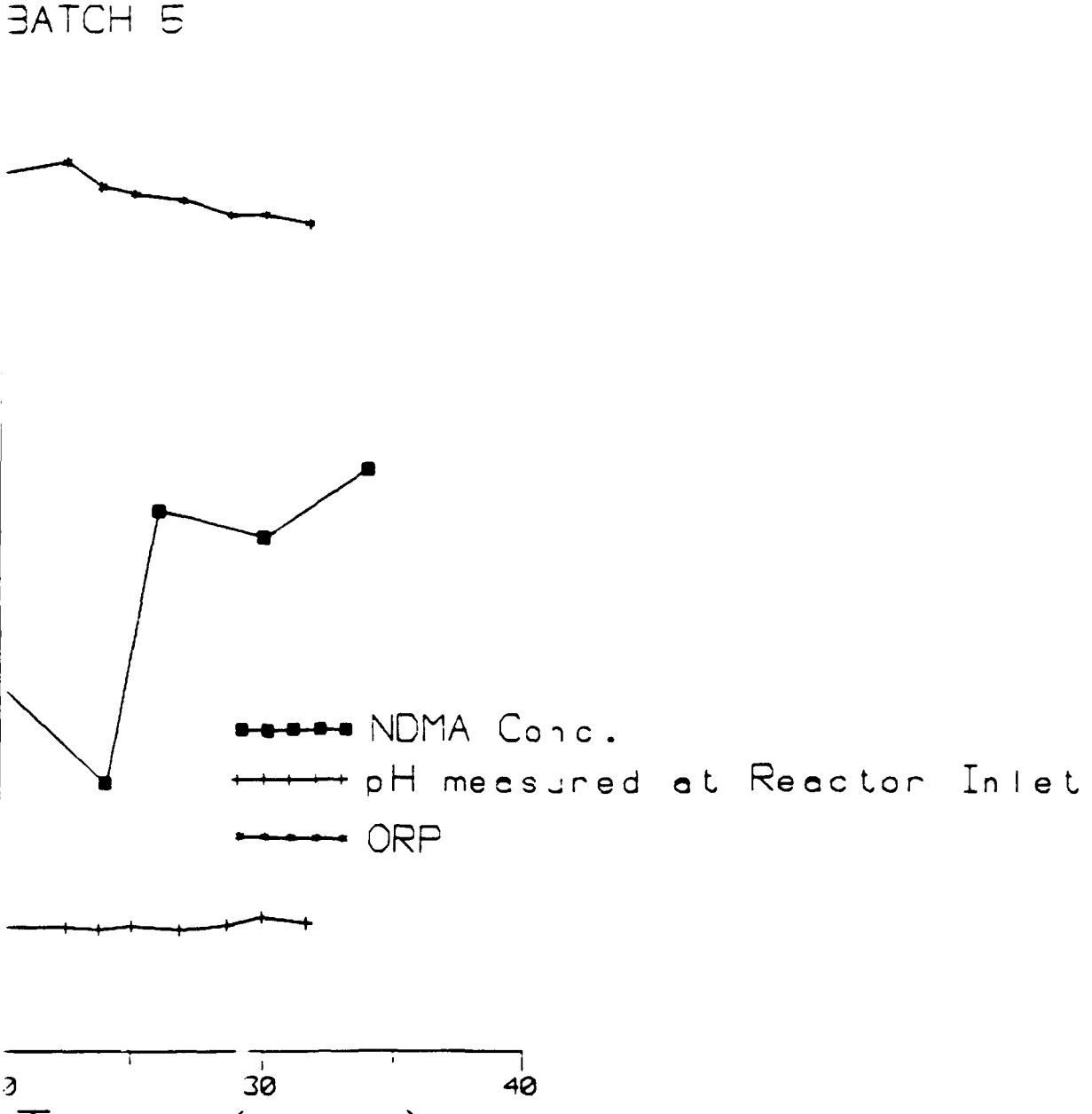

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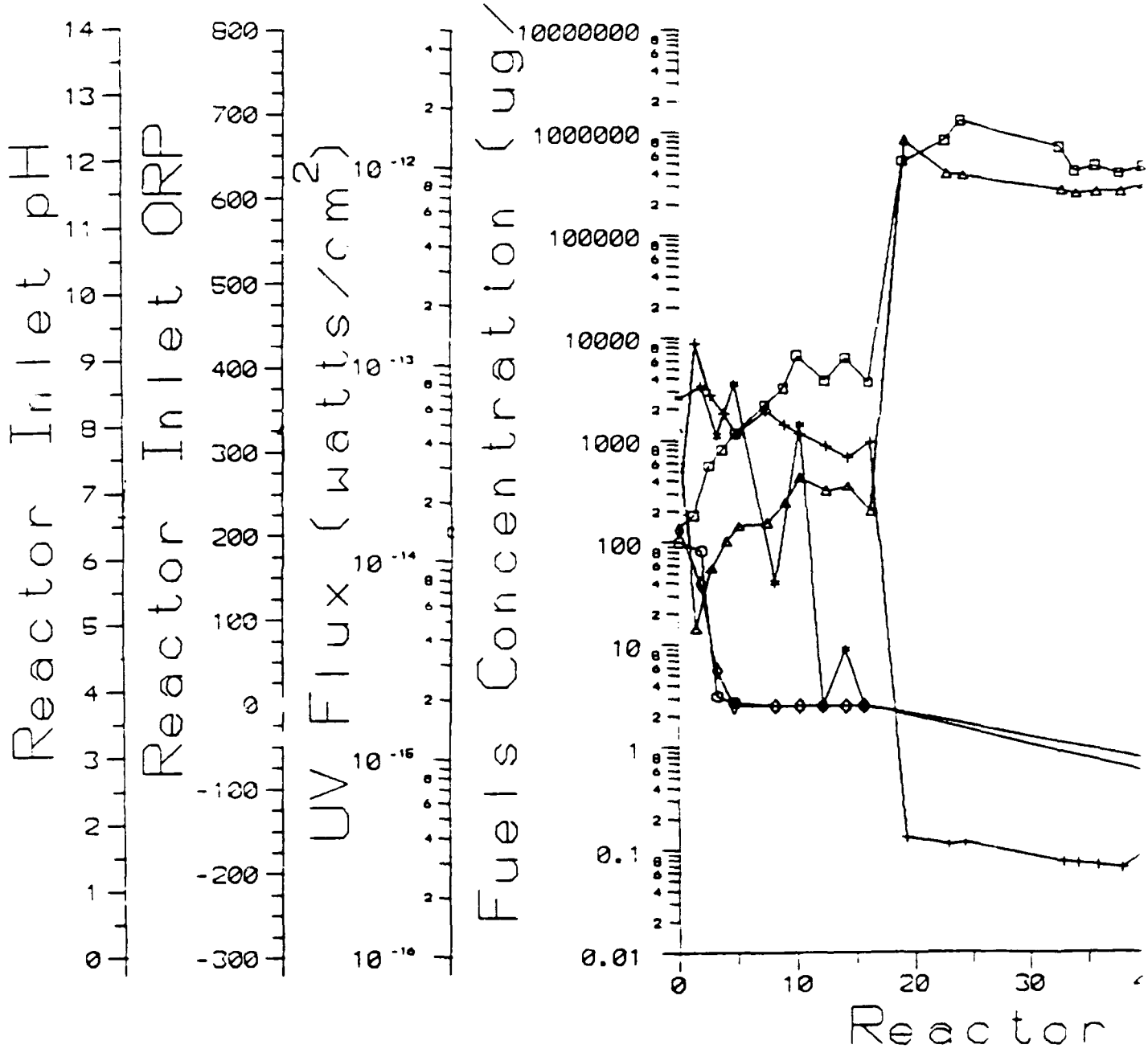
Figure 7.6
REACTOR INLET pH, REACTOR INLET ORP, AND NDMA CONCENTRATION VS. REACTOR TIME – BATCH 5



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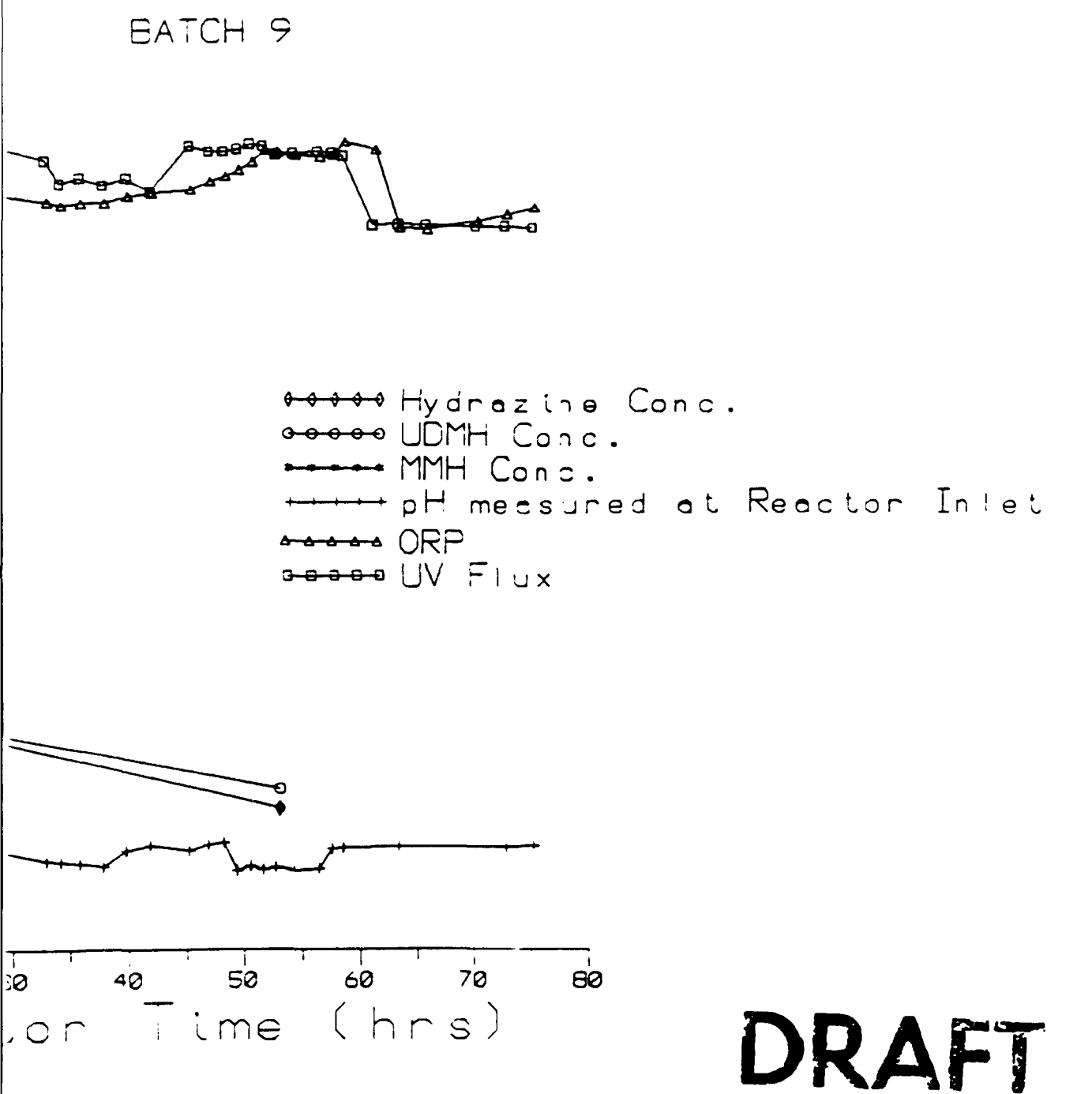

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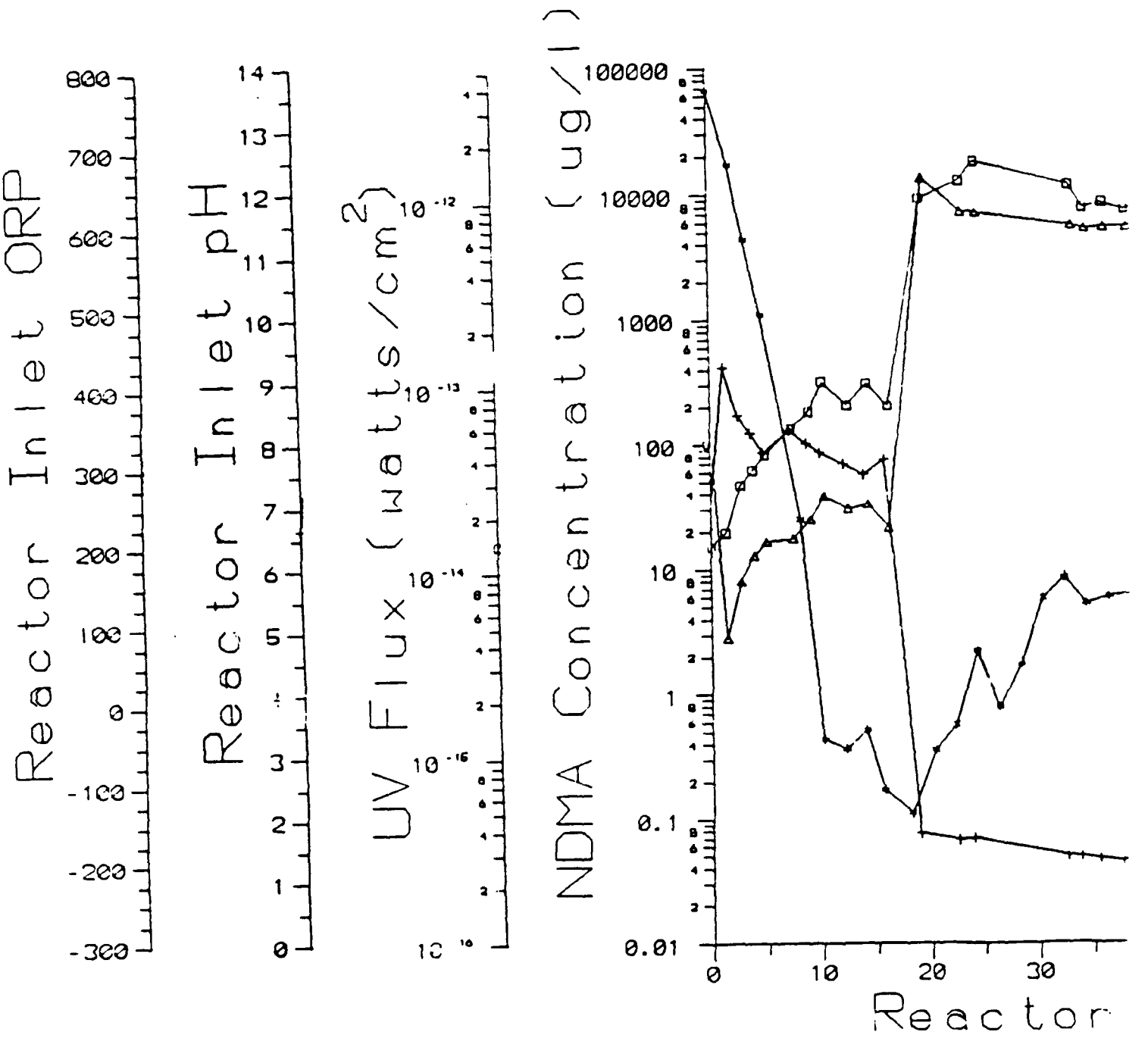
Figure 7.7
REACTOR INLET pH, REACTOR INLET ORP, UV FLUX, AND HYDRAZINE FUEL COMPOUNDS CONCENTRATIONS VS. REACTOR TIME - BATCH 9



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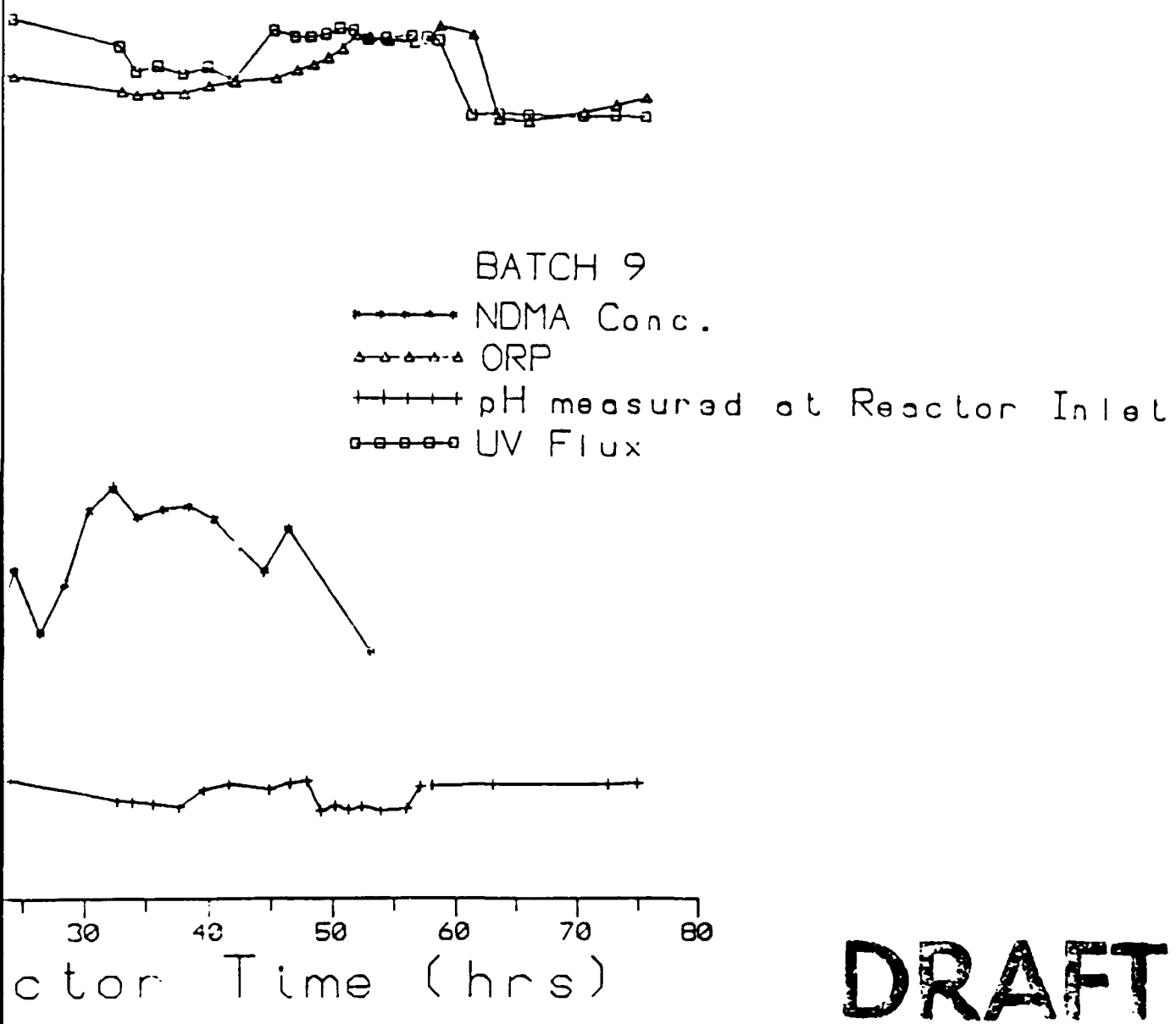

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Figure 7.8
REACTOR INLET pH, REACTOR INLET ORP, UV FLUX, AND NDMA CONCENTRATION VS. REACTOR TIME – BATCH 9

of the batch. For batch 9, hydrogen peroxide concentrations averaged 8400 mg/l during the treatment period between 32 and 40 hours.

The results from treatment of hydrazine wastewater batches 3, 4, 5, and 9 show that the rate of destruction of the hydrazine fuel compounds is optimum at pH values greater than 8.5. Hydrazine fuel solutions have pH values that are strongly basic and ORPs that are reducing (Encyclopedia of Chemical Technology, 1978b). As shown in Figures 7.1, 7.3, and 7.7, destruction of the hydrazine fuel compounds is indicated by a decrease in influent wastewater pH to a near neutral value and an increase in ORP to an oxidizing value in the +300 mv range. Thus, it can be concluded that when evaluating UV/chemical oxidation system performance with respect to completeness of hydrazine fuel compound destruction (1) pH is reduced to a near neutral value, (2) ORP is a positive value (greater than 300 mv), and (3) consumption of hydrogen peroxide is constant.

The destruction of NDMA could not be measured by any of the operating parameters (i.e., pH, ORP, and hydrogen peroxide concentration) that may be used to indicate reduction of the hydrazine fuel compounds. The rate of destruction of NDMA appears to be dependent on the concentration of NDMA in the untreated wastewater and on treatment time. As shown in Figures 7.2, 7.4, and 7.8, operation of the UV/chemical oxidation treatment system for batches 3, 4, and 9 showed a direct relationship between influent NDMA concentrations and treatment times for NDMA destruction.

7.3.3 Corrosion

Corrosion of the UV/chemical oxidation reactor occurred during the full-scale startup testing program. Corrosion was detected at welded seams in the reactor and in components manufactured from 304 stainless steel. Components containing 304 stainless steel and in contact with the wastewater were replaced during the course of full-scale startup testing with components fabricated of CPVC or 316L stainless steel.

7.3.4 Air-Monitoring Results

Results of the air monitoring indicate that hydrazine fuel compounds and NDMA were present in the facility air during Phase I operations. Maximum concentrations detected were related to downtime for piping repairs, equipment failures, and facility cleanup after equipment failures. Inadvertant releases related to piping repairs and equipment failure during future full-scale operations will be minimized with upgraded equipment and simplified equipment layout.

7.3.4.1 Nonreal-Time Monitoring

During treatment of the first two wastewater batches, several locations throughout the WWTF were monitored:

1. Between tanks T-101 and T-102, intermediate holding tanks for treated wastewater (for NDMA and hydrazine fuel compounds)
2. Near tank T-101, untreated wastewater storage tank (for NDMA only)
3. Between the reactor R-201 and the recycle tank T-201 (for NDMA and hydrazine fuel compounds)
4. Between tanks T-401 and T-402, seal-water tanks for offgas collection (for NDMA and hydrazine compounds)

These locations were selected as likely sources of fugitive emissions. Because hydrazine, MMH, and UDMH vapors are heavier than air and were expected to accumulate along the floor in the absence of air movement, air sampling pumps and cartridges were placed at floor level. Sampling pumps for NDMA were also located at floor level to obtain comparable data with respect to location.

If significant differences in contaminant concentrations at locations throughout the facility were apparent, it would indicate a potential breach in the integrity of the equipment at that location. As shown in Appendix B, the respective concentrations of hydrazine fuel compounds and NDMA in air were nearly identical at each of the four monitoring locations during treatment of batches 1 and 2.

During the remainder of the full-scale startup testing program, the primary location within the facility to be monitored for hydrazine fuel compounds and NDMA was on top of the UV/chemical oxidation reactor, approximately 6 feet above the facility floor. Because of the similar concentrations obtained at the initial four monitoring locations during treatment of the first two batches, this location was considered representative of the general air quality within the facility. Additionally, air movement during treatment operations within the WWTF was significant, particularly when the chiller was operating. Concentrations of air contaminants above the reactor were not expected to be different from concentrations that may have been present at floor level. Air-monitoring results for the hydrazine fuel compounds and NDMA are presented in Appendix B.

Hydrazine, MMH, UDMH, and NDMA were all detected in the air within the WWTF. Low concentrations of hydrazine fuel compounds were occasionally detected. As shown in Appendix B, the maximum concentrations of hydrazine, MMH, and UDMH were detected just before treatment of batch 4. This occurred when the radiometer plug on the reactor failed during transfer of untreated wastewater into the reactor, releasing wastewater within the contained area around the reactor. However, the concentrations of hydrazine fuel compounds in air as a result of this equipment failure were, at most, 150 times less than their respective PELs and were not expected to present any risks to operations personnel.

Unlike the hydrazine fuel compounds, NDMA was consistently detected during startup testing at concentrations ranging from less than 0.1 $\mu g/m^3$ to 38 $\mu g/m^3$. Typical air concentrations of NDMA were generally less than 2.0 $\mu g/m^3$. The higher concentrations of NDMA in air that were detected were related to activities involving piping repairs. Air concentrations of NDMA were generally highest during the initial hours of treatment and decreased as treatment time progressed. Two factors that may have caused this observed pattern are as follows: (1) the concentration of NDMA in wastewater initially increases when treatment begins and decreases as treatment time progresses and (2) ventilation of the facility during treatment continuously decreases NDMA concentrations in the air.

7.3.4.2 Real-Time Air Monitoring for Hydrazine Fuel Compounds

UDMH was not detected by the TLD-1 detector any time during the Phase I startup testing period. However, as mentioned, this detector was also used to monitor for MMH. Hydrazine and MMH were detected at times during the changing of the bag filters, influent sampling, and piping repairs. Maximum detections were approximately 20 ppb hydrazine and 20 ppb MMH. Because of the short duration of these air concentrations, they were not reflected in any of the ThermoSorb cartridge samples that were collected at the same time.

From approximately 3:30 p.m. on February 24, 1990, through approximately 9:00 a.m. on February 25, 1990, the air concentration of hydrazine within the WWTF varied from 20 to 40 ppb, as recorded by the TLD-1 detector located above the UV/chemical oxidation reactor. This concentration is less than 50 percent of the PEL for hydrazine. MMH was not detected during this time, but personnel were not working at the facility. These hydrazine air concentrations were detected after wastewater was transferred from tank T-101 into the reactor and tank T-201 on the afternoon of February 24, 1990. Failure of an in-line O-ring and a check valve resulted in a release of untreated wastewater from the reactor/recycle tank system within the secondary containment around the reactor. ThermoSorb air sampling cartridges were not being used during this time and thus cannot be compared with TLD-1 monitoring results.

On March 14, 1990, during the transfer of wastewater in preparation for treatment of batch 4, the seal on the radiometer plug on the reactor failed, releasing approximately 10 gallons of untreated wastewater into the secondary containment around the reactor. The TLD-1 detectors recorded a maximum excursion of approximately 40 ppb for hydrazine and 30 ppb for MMH.

Photocopies of the TLD-1 strip charts for the events described above are provided in Appendix B as examples of the real-time monitoring results.

7.3.4.3 Hydrazine Detection Badges and Hydrazine Colorimetric Tubes

A color change from white to yellow, orange, or red was frequently observed on the hydrazine detection badges placed throughout the facility. The most intense color changes occurred on badges located near recycle pump P-201 and recycle tank T-201. As distance from

the recycle pump increased, the intensity of the color change decreased. Similarly, badges worn by operations personnel frequently changed color. Most of the plant and personnel badge color changes occurred during treatment of batches 1 through 4. Mechanical and piping modifications were less frequent during treatment of batches 5 through 9.

Detector tubes indicated hydrazine concentrations as high as 300 ppb during the changing of bag filters and 100 ppb near recycle pump P-201 during wastewater treatment. Most detector tube results were less than the detection limit of 50 ppb.

Results from the detector tube evaluations tend to support the color change on the hydrazine detection badges located near the reactor. However, color change on the paper badges was not observed to be correlated with the results of the ThermoSorb cartridge sampling or the real-time MDA TLD-1 detectors. As indicated in Section 7.3.4.2, the TLD-1 detector recorded concentrations of hydrazine of between 20 and 40 ppb the night of February 24, 1990, when untreated wastewater was released into the secondary containment around the reactor. These values are less than one-half the PEL for hydrazine. During this same time period, all paper hydrazine detection badges in the facility turned yellow/orange. It is possible that the paper badges turn color as a result of extended and cumulative exposure to hydrazine concentrations that are less than the PEL.

Additionally, ThermoSorb cartridge analyses for hydrazine did not indicate hydrazine concentrations above 0.25 ppb in the facility air during any treatment operations. This concentration of hydrazine is less than the estimated limit of detection for the real time TLD-1 monitors. ThermoSorb cartridge sample results are averaged over 8 to 12 hours and do not identify short-term excursions.

In summary, although the hydrazine detection badges provided a qualitative evaluation that facility air hydrazine concentrations may have exceeded the PEL, neither the time-weighted average results from the ThermoSorb cartridges or the MDA TLD-1 hydrazine monitors (which provide 15-minute interval results) support the badge results. Concentrations of hydrazine, MMH, and UDMH detected using the Thermosorb cartridges and the MDA TLD-1 monitors were, at all times, less than the PEL. Risks to operations personnel are expected to be negligible.

7.3.4.4 Photoionization Monitoring

VOCs were detected only one time during full-scale startup testing when monitoring with a PID. When wastewater is transferred from storage tank US-4 into the untreated wastewater storage tank T-101, the displaced air volume from T-101 is routed through the seal water module and vented into the hydrazine WWTF. During transfer of the first batch of wastewater into T-101, 20 to 100 ppm VOCs were detected exiting the seal-water vent. A series of vapor-phase GAC filters were connected to the seal-water tank vent piping before treatment of batch 2. When batch 2 was transferred from tank US-4 to tank T-101 before treatment, no VOCs were detected at the discharge from the vapor-phase GAC filters by PID monitoring. Additional air sampling and analysis for VOCs using a sampling pump and an activated charcoal tube placed at the seal-water tank vent did not indicate the presence of VOCs in subsequent batches.

PID monitoring at other areas of the facility (e.g., around the UV/chemical oxidation reactor, the recycle tank, and wastewater storage tanks) during full-scale startup testing did not indicate the presence of VOCs. Routine monitoring for VOCs was not continued after treatment of batch 3.

7.3.5 QA/QC Analytical Results Summary

Full-scale startup testing analytical results for trip, field, and rinse blanks are presented in Table 7.3. Two trip blank samples were analyzed for NDMA only. Trip blank results indicate that the influence of transportation of low- and high-level concentration samples did not adversely affect investigative sample results. Trip blanks were not analyzed for hydrazine fuel compounds because no evidence of carry-over cross-contamination was observed for the hydrazine fuel compounds during batches 1 and 2 analyses. Eleven field blank samples were similarly analyzed for the presence of NDMA only. NDMA was detected in three of the 11 field blank samples analyzed. Results from the field blank analyses included in Table 7.3 indicate that ambient air conditions at the time of sampling did not adversely affect investigative sample analytical results. One sample, IRAH-18-1, indicated the presence of NDMA at a concentration of 3.37 μg/l. This sample was collected in the hydrazine WWTF during collection of influent

Table 7.3: Full-Scale Startup Testing Program Analytical Results for Trip, Field, and Rinse Blanks

Sample Identification	Type of Blank	Batch Number	Target Analyte Concentration (µg/l) NDMA	Hydrazine	UDMH	MMH
IRAH-09-I	Trip	3	< 0.020	N/A	N/A	N/A
IRAH-11-E	Trip	3	0.037	N/A	N/A	N/A
IRAH-10-I	Field	3	0.116	N/A	N/A	N/A
IRAH-14-KA	Field	3	<0.020	N/A	N/A	N/A
IRAH-12-E	Field	3	0.036	N/A	N/A	N/A
IRAH-14-E	Field	3	<0.020	N/A	N/A	N/A
IRAH-12-I	Field	4	0.302	N/A	N/A	N/A
IRAH-18-KA	Field	4	< 0.020	N/A	N/A	N/A
IRAH-26-KA	Field	4	< 0.020	< 0.25	< 0.25	< 0.25
IRAH-18-E	Field	4	< 0.020	N/A	N/A	N/A
IRAH-21-E	Field	6	< 0.020	N/A	N/A	N/A
IRAH-07-C	Field	8	0.033	N/A	N/A	N/A
IRAH-18-I	Field	9	3.37	N/A	N/A	N/A
IRAH-14-E	Rinse	3	< 0.020	N/A	N/A	N/A
IRAH-17-KA	Rinse	4	0.174	N/A	N/A	N/A
IRAH-25-KA	Rinse	4	< 0.020	< 0.25	< 0.25	< 0.25
IRAH-17-E	Rinse	4	< 0.020	N/A	N/A	N/A

NDMA = n-nitrosodimethylamine
UDMH = unsymmetrical dimethyl hydrazine
MMH = monomethyl hydrazine
µg/l = micrograms per liter (or parts per billion)
N/A = not analyzed
< = analyte not detected at or above method reporting limits

wastewater samples for batch 9. The measured NDMA concentration in the batch 9 influent wastewater investigative sample, IRAH-17-I, was 66,000 μg/l. Accordingly, the net effect of the observed field blank contamination concentration of 3.37 μg/l on the reported analytical results is negligible.

Field blank sample, IRAH-12-I, which contained NDMA at a concentration of 0.302 μg/l, is also associated with a high concentration influent sample, and the net effect on the associated investigative sample result is considered negligible. Field blank sample IRAH-12-E, which contained NDMA at a concentration of 0.036 μg/l, is not directly related to the analytical results for treatment process samples.

The remaining field blank analyses results indicate that no adverse effects on the reported analytical results occurred during sampling of process effluent. Due to the fact that ambient air conditions did not appear to affect analytical results, trip blanks scheduled for later runs were canceled and field blanks were used to characterize both the effects of transport and ambient air conditions on investigative sample results. A single field blank (IRAH-26KA) was analyzed for the presence of hydrazine fuel compounds. The results of this analysis showed that hydrazine fuel compounds were not detected above MRLs and confirmed that no adverse effects with respect to hydrazines in air occurred.

Results from analysis of four rinse blanks during the Phase I program are provided in Table 7.3. Investigative sample results related to the single positive result for a rinse blank (IRAH-17-E) listed in Table 7.3 were several orders of magnitude above the 0.174 μg/l of NDMA reported for this rinse blank. Consequently, the net effect of sampling conditions, as evidenced in rinse blank results, on the reported investigative analytical results is considered negligible.

Duplicate sample results are presented in Table 7.4. Duplicate samples were analyzed for NDMA and hydrazine fuel compounds. The mean and duplicate sample agreement (DSA) were calculated and provided in Table 7.4. DSA was calculated by taking the absolute value of the two replicate values and dividing by the mean or average of the replicate values. From the results shown in Table 7.4, DSA values for NDMA ranged from 1.39 to 162 percent. DSA values for

Table 7.4: Full-Scale Startup Testing Program Duplicate Sample Results
(Page 1 of 4)

Batch Number	Sample Identification	NDMA Concentration (µg/l)	Mean Concentration (µg/l)	Duplicate Sample Agreement (µg/l)	Results of Dixon's Outlier Test[1] (µg/l)
1	IRAH-02-E	N/A			
	IRAH-02-E (Duplicate)	1.18	1.18	N/A	No
2	IRAH-06-E	0.34			
	IRAH-06-E (Duplicate)	0.26	0.30	27.4	No
3	IRAH-05-KB	190.			
	IRAH-05-KB (Duplicate)	187.	189.	1.59	No
	IRAH-11-KB	30.0			
	IRAH-11-KB (Duplicate)	44.2	37.1	38.3	No
	IRAH-17-KB	31.5			
	IRAH-17-KB (Duplicate)	30.2	30.9	4.21	No
	IRAH-02-KA	0.11			
	IRAH-02-KA (Duplicate)	0.08	0.10	32.5	No
	IRAH-07-KA	0.84			
	IRAH-07-KA (Duplicate)	0.15	0.49	140.	No
	IRAH-09-E	5.81			
	IRAH-09-E (Duplicate)	12.1	8.96	70.2	No
	IRAH-13-E	4.09			
	IRAH-13-E (Duplicate)	3.28	3.69	22.0	No
4	IRAH-15-KA	173.			
	IRAH-15-KA (Duplicate)	147.	160.	16.3	No
	IRAH-23-KA	1.73			
	IRAH-23-KA (Duplicate)	2.34	2.04	30.0	No
	IRAH-15-E	0.62			
	IRAH-15-E (Duplicate)	0.47	0.54	28.2	No
	IRAH-03-C	0.81			
	IRAH-03-C (Duplicate)	7.82	4.32	162.	No
9	IRAH-25-E	0.57			
	IRAH-25-E (Duplicate)	0.58	0.58	1.39	No

Table 7.4: (Page 2 of 4)

Batch Number	Sample Identification	NDMA Concentration (µg/l)	Mean Concentration (µg/l)	Duplicate Sample Agreement (µg/l)	Results of Dixon's Outlier Test[1] (µg/l)
1	IRAH-02-E	2.50			
	IRAH-02-E (Duplicate)	2.50	2.50	0.00	No
3	IRAH-05-KB	2.50			
	IRAH-05-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-11-KB	2.50			
	IRAH-11-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-17-KB	2.50			
	IRAH-17-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-02-KA	2.50			
	IRAH-02-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-07-KA	2.50			
	IRAH-07-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-09-E	2.50			
	IRAH-09-E (Duplicate)	2.50	2.50	0.00	No
4	IRAH-15-KA	4.00			
	IRAH-15-KA (Duplicate)	0.97	2.49	122	No
	IRAH-23-KA	0.25			
	IRAH-23-KA (Duplicate)	0.73	0.49	98.0	No
	IRAH-15-E	0.94			
	IRAH-15-E (Duplicate)	0.53	0.74	55.8	No
9	IRAH-25-E	0.25			
	IRAH-25-E (Duplicate)	0.25	0.25	0.00	No

Table 7.4: (Page 3 of 4)

Batch Number	Sample Identification	NDMA Concentration (µg/l)	Mean Concentration (µg/l)	Duplicate Sample Agreement (µg/l)	Results of Dixon's Outlier Test[1] (µg/l)
1	IRAH-02-E	2.50			
	IRAH-02-E (Duplicate)	2.50	2.50	0.00	No
3	IRAH-05-KB	2.50			
	IRAH-05-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-11-KB	2.50			
	IRAH-11-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-17-KB	2.50			
	IRAH-17-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-02-KA	2.50			
	IRAH-02-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-07-KA	2.50			
	IRAH-07-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-09-E	2.50			
	IRAH-09-E (Duplicate)	2.50	2.50	0.00	No
4	IRAH-15-KA	5.30			
	IRAH-15-KA (Duplicate)	0.78	3.04	149	No
	IRAH-23-KA	0.25			
	IRAH-23-KA (Duplicate)	0.25	0.25	0.00	No
	IRAH-15-E	0.45			
	IRAH-15-E (Duplicate)	0.25	0.35	57.1	No
9	IRAH-25-E	0.25			
	IRAH-25-E (Duplicate)	0.39	0.32	43.8	No

Table 7.4: (Page 4 of 4)

Batch Number	Sample Identification	NDMA Concentration (µg/l)	Mean Concentration (µg/l)	Duplicate Sample Agreement (µg/l)	Results of Dixon's Outlier Test[1] (µg/l)
1	IRAH-02-E	2.90			
	IRAH-02-E (Duplicate)	2.50	2.70	14.81	No
3	IRAH-05-KB	2.50			
	IRAH-05-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-11-KB	2.50			
	IRAH-11-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-17-KB	2.50			
	IRAH-17-KB (Duplicate)	2.50	2.50	0.00	No
	IRAH-02-KA	2.50			
	IRAH-02-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-07-KA	2.50			
	IRAH-07-KA (Duplicate)	2.50	2.50	0.00	No
	IRAH-09-E	2.50			
	IRAH-09-E (Duplicate)	2.50	2.50	0.00	No
4	IRAH-15-KA	8.20			
	IRAH-15-KA (Duplicate)	6.70	7.45	20.1	No
	IRAH-23-KA	0.87			
	IRAH-23-KA (Duplicate)	0.70	0.79	21.7	No
	IRAH-15-E	0.85			
	IRAH-15-E (Duplicate)	0.35	0.60	83.3	Yes
9	IRAH-25-E	0.25			
	IRAH-25-E (Duplicate)	0.25	0.25	0.00	No

NDMA = n-nitrosodimethylamine
µg/l = micrograms per liter (or parts per billion)

[1] Outlier = Data outliers for the Duplicate Sample Agreement (DSA) values were determined using Dixon's Outlier Test as described in the PMRMA Chemical Quality Assurance Program, Version 1.0, 1989
No - indicates duplicate sample ageement is not a Dixon outlier as compared to the entire data set
Yes - indicates duplicate sample ageement is a Dixon outlier as compared to the entire data set

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hydrazine ranged from 0.0 to 122 percent. DSA values for UDMH ranged from 0.0 to 149 percent. A review of the general distribution of the reported DSA values indicates that analytical variability is more pronounced in the NDMA analyses than in the hydrazine analyses. This is presumably due to the volatilization of NDMA during analysis and sample collection.

Method blank results for NDMA are presented in Table 7.5. NDMA method blank results shown in Table 7.5 are presented with the related investigative sample concentration and NDMA blank-corrected sample concentration. The net effect of method blank contamination on the reported investigative sample results was evaluated by subtracting the method blank concentration adjusted for the dilution factor from the reported investigative sample concentration. The results of this evaluation are plotted for each of the affected batches in Figures 7.9 through 7.12. Results of the evaluation indicate that batch 9 shows the highest degree of uncertainty, due to NDMA method blank contamination. No method blank contamination concerns such as those experienced for NDMA were observed for any of the other analytical methods employed during Phase I.

Two MS/MSD sample analyses for NDMA were performed. In the first set of spiked sample analyses, the related investigative sample native NDMA concentration was 1.73 μg/l. The amount of NDMA spiked into all MS and MSD samples was 0.110 μg/l. The results for the MS and MSD were 1.50 and 1.82 ppb, respectively. In the second set of MS/MSD samples analyzed, the related investigative sample native NDMA concentration was 0.562 μg/l and the MS/MSD results are 0.724 and 0.522 μg/l, respectively. Results for these two MS/MSD analyses indicate that the concentration of NDMA in investigative samples masked the MS concentration added to the respective MS/MSD samples. Because of the high concentration of NDMA in the investigative samples compared to the low spiked concentration, it was not possible to evaluate method precision and accuracy for NDMA. Future MS/MSD spiking levels will be increased when analyzing samples containing medium to high levels of NDMA.

Laboratory audits performed during Phase I revealed that analytical data packages contained all required deliverables. Methods were found to have been performed in accordance with the requirements of the program. NDMA method blank contamination was identified during

Table 7.5: Hydrazine Blending and Storage Facility
Method Blank Summary for N-Nitrosodimethylamine, Phase I
(Page 1 of 5)

Blank Identification	Related Investigative Sample Identification	Method Blank Concentration[1]	Related Investigative Sample Concentration[1]	Dilution Factor	Blank-Corrected Investigative Sample Concentration[1]
IOJ001		<.200			
	IRAH-01-I		120	1000	120
IPQ001		<.200			
	IRAH-03-E		.600	10	.600
IRJ001		<.042			
	IRAHUS3-C		790	10000	790
	IRAHUS3-A		610	10000	610
	IRAHUS3-D		500	10000	500
	IRAHUS3-B		470	10000	470
	IRAHUS4-A		60.0	500	60.0
	IRAHUS4-B		56.0	500	56.0
	IRAHUS4-C		53.0	500	53.0
	IRASUMP-3		5.80	40	5.80
	IRASUMP-1		4.40	40	4.40
	IRASUMP-2		2.20	40	2.20
	IRASUMP-4		1.40	20	1.40
	IRAH-04-E		.230	4	.230
ITB001		<.042			
	IRAH-05-E		.530	10	.530
IUW001		<.020			
	IRAH-06-E		2.50	80	2.50
	IRAH-07-E		.690	20	.690
IWT001		.086			
	IRAH-01-KB		8280	20000	6560
	IRAH-02-KB		5300	20000	3580
	IRAH-03-KB		880	5000	450
	IRAH-04-KB		625	5000	195
	IRAH-08-I		285	1000	199
	IRAH-05-KB		190	1000	104
	IRAH-06-KB		187	1000	101
	IRAH-07-KB		87.9	1000	1.90
	IRAH-08-KB		52.6	100	44.0
	IRAH-09-KB		30.0	100	21.4
	IRAH-10-KB		27.4	100	18.8
	IRAH-10-I		.116	1	.030
	IRAH-09-I		.017	1	-.069

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Table 7.5: (Page 2 of 5)

Blank Identification	Related Investigative Sample Identification	Method Blank Concentration[1]	Related Investigative Sample Concentration[1]	Dilution Factor	Blank-Corrected Investigative Sample Concentration[1]
IXL001		<.020			
	IRAH-14-KB		50.0	500	50.0
	IRAH-12-KB		44.2	500	44.2
	IRAH-15-KB		43.3	500	43.3
	IRAH-13-KB		41.9	500	41.9
	IRAH-17-KB		31.5	500	31.5
	IRAH-18-KB		30.2	500	30.2
	IRAH-11-KB		30.0	1000	30.0
	IRAH-16-KB		29.4	500	29.4
	IRAH-02-KA		.114	1	.114
	IRAH-03-KA		.082	1	.082
	IRAH-14-KA		< .020	1	<.020
IXW001		.022			
	IRAH-10-E		12.1	10	11.9
	IRAH-09-E		5.81	10	5.59
	IRAH-11-E		.037	1	.015
	IRAH-12-E		.036	1	.014
IXX001		<.020			
	IRAH-08-KA		.839	10	.839
	IRAH-04-KA		.255		.255
	IRAH-06-KA		.234	10	.234
	IRAH-10-KA		.203	1	.203
	IRAH-11-KA		.163	1	.163
	IRAH-07-KA		.148	5	.148
	IRAH-09-KA		.132	1	.132
	IRAH-13-KA		.127	1	.127
	IRAH-12-KA		.100	1	.100
	IRAH-05-KA		.062		.062
JAC001		<.020			
	IRAH-13-E		3.28	20	3.28
	IRAH-14-E		< .020	1	<.020
JDQ001		<.020			
	IRAH-15-KA		173	500	173
	IRAH-23-KA		1.73	10	1.73
	IRAH-29-KA		1.20	10	1.20

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Table 7.5: (Page 3 of 5)

Blank Identification	Related Investigative Sample Identification	Method Blank Concentration[1]	Related Investigative Sample Concentration[1]	Dilution Factor	Blank-Corrected Investigative Sample Concentration[1]
JDR001		.123			
	IRAH-11-I		23400	1	23400
	IRAH-21-KB		13000	1	13000
	IRAH-23-KB		9190	1	9190
	IRAH-25-KB		5910	1	5910
	IRAH-16-KA		147	1	147
	IRAH-19-KA		47.7	1	47.6
	IRAH-20-KA		8.79	1	8.67
	IRAH-22-KA		4.32	1	4.20
	IRAH-24-KA		2.34	1	2.22
	IRAH27KAMS		1.82	1	1.70
	IRAH-27-KA		1.50	1	1.38
	IRAH-12-I		.302	1	.179
	IRAH-17-KA		.174	1	.051
	IRAH-18-KA		< .020	1	<.020
	IRAH-25-KA		< .020	1	<.020
	IRAH-26-KA		< .020	1	<.020
JDU001		<.020			
	IRAH-31-KA		.738	10	.738
	IRAH19EMS		.724	10	.724
	IRAH-15-E		.562	10	.562
	IRAH19EMSD		.522	10	.522
	IRAH-16-E		.467	10	.467
	IRAH-17-E		< .020	1	<.020
	IRAH-18-E		.020	1	.020
JEP001		.043			
	IRAH-38-KA		63.1	100	58.8
	IRAH-39-KA		.679	10	.249
JER001		.403			
	IRAH-13-I		59200	40000	43080
	IRAH-33-KA		41500	50000	21350
	IRAH-34-KA		5200	5000	3185
	IRAH-35-KA		4000	5000	1985
	IRAH-36-KA		1480	1000	1077
	IRAH-37-KA		514	1000	111
JES001		<.020			
	IRAH-44-KA		101	500	101
	IRAH-40-KA		51.9	1000	51.9
	IRAH-42-KA		33.6	500	33.6

Table 7.5: (Page 4 of 5)

Blank Identification	Related Investigative Sample Identification	Method Blank Concentration[1]	Related Investigative Sample Concentration[1]	Dilution Factor	Blank-Corrected Investigative Sample Concentration[1]
JFN001		<.020			
	IRAH-14-I		40000	50000	40000
	IRAH-15-I		28300	50000	28300
JFO001		<.020			
	IRAH-20-E		25.8	20	25.8
	IRAH-21-E		<.020	1	<.020
JFZ001		<.020			
	IRAH-23-E		1.39	20	1.39
JHQ001		.040			
	IRAH-03-C		7.82	10	7.42
	IRAH-01-C		3.03	10	2.63
	IRAH-02-C		.978	1	.938
	IRAH-04-C		.812	1	.772
	IRAH-07-C		.032	1	-.003
JIL001		.089			
	IRAH-5-C		.149	.149	
JJJ001		.084			
	IRAH-24-E		6.30	10	5.46
JJL001		.088			
	IRAH-16-I		3800	1000	3712
JKC001		.263			
	IRAH-17-I		66000	20000	60740
	IRAH-27-KB		17200	10000	14570
	IRAH-28-KB		4390	10000	1760
	IRAH-29-KB		1090	10000	-1540
	IRAH-30-KB		25.0	50	11.8
	IRAH-31-KB		22.0	50	8.85
	IRAH-32-KB		18.5	50	5.35
	IRAH-45-KB		8.30	50	-4.85
	IRAH-48-KA		5.70	10	3.07
	IRAH-33-KB		5.21	10	2.58
	IRAH-47-KA		3.59	10	.960
	IRAH-18-I		3.37	10	.740

Table 7.5: (Page 5 of 5)

Blank Identification	Related Investigative Sample Identification	Method Blank Concentration[1]	Related Investigative Sample Concentration[1]	Dilution Factor	Blank-Corrected Investigative Sample Concentration[1]
	IRAH-46-KA		1.07	10	-1.56
JKK001		.089			
	IRAH-53-KA		8.36	10	7.47
	IRAH-56-KA		6.19	10	5.30
	IRAH-55-KA		5.92	10	5.03
	IRAH-52-KA		5.78	10	4.89
	IRAH-54-KA		5.21	10	4.32
	IRAH-57-KA		4.99	10	4.10
	IRAH-60-KA		4.27	10	3.38
	IRAH-58-KA		3.17	10	2.28
	IRAH-49-KA		2.21		2.21
	IRAH-59-KA		2.12	10	1.23
	IRAH-51-KA		1.76		1.76
	IRAH-50-KA		.783		.783

[1] concentrations in micrograms per liter (µg/l)

Blank Corrected Concentration = (Sample Conc) - (Blank Conc * Dilution Factor)
No Correction Factor applied to nondetect blanks
< = analyte not detected at or above method reporting limits

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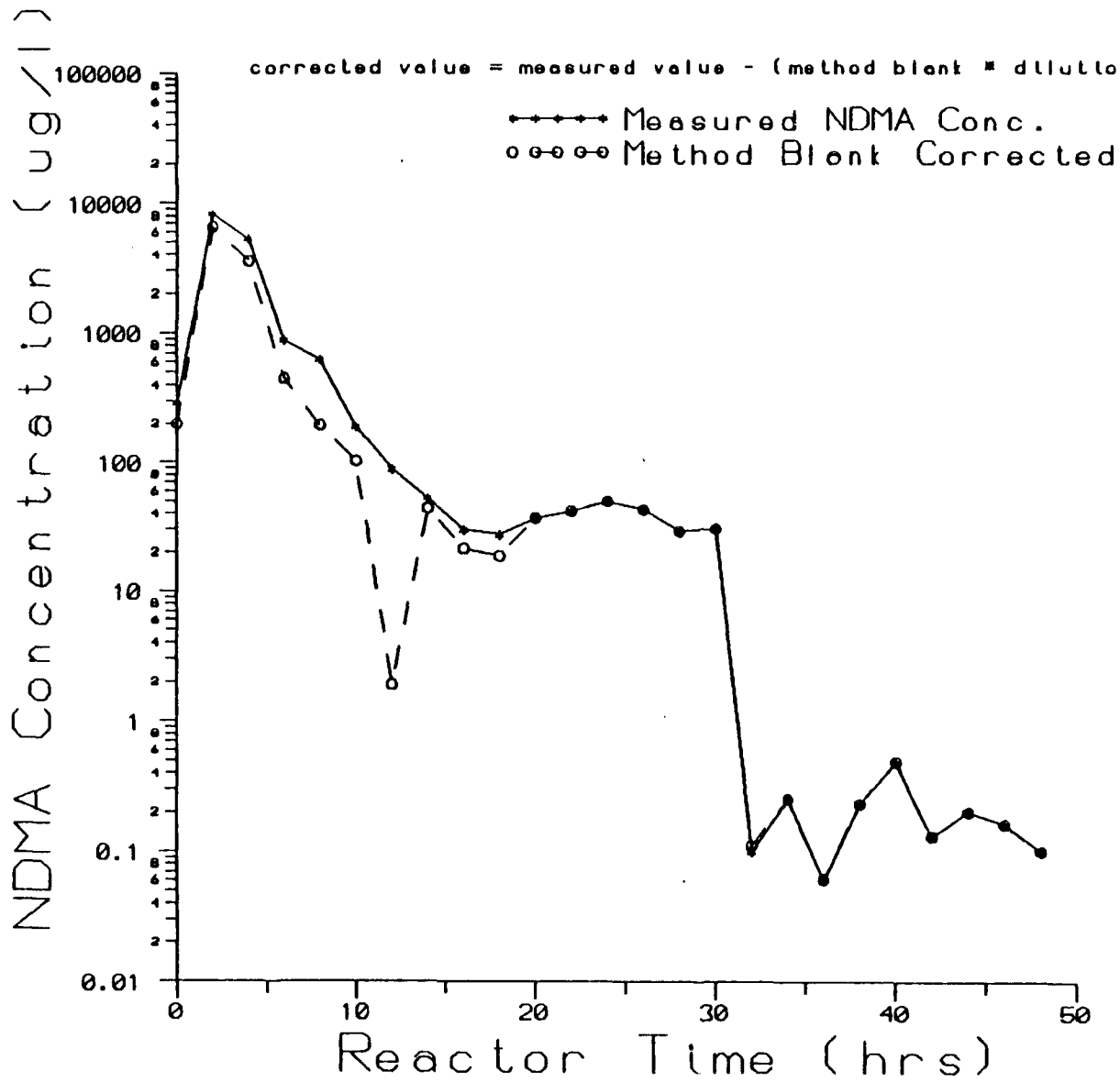

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Figure 7.9

BLANK-CORRECTED CHEMICAL CHARACTERIZATION CURVES FOR NDMA IN BATCH 3

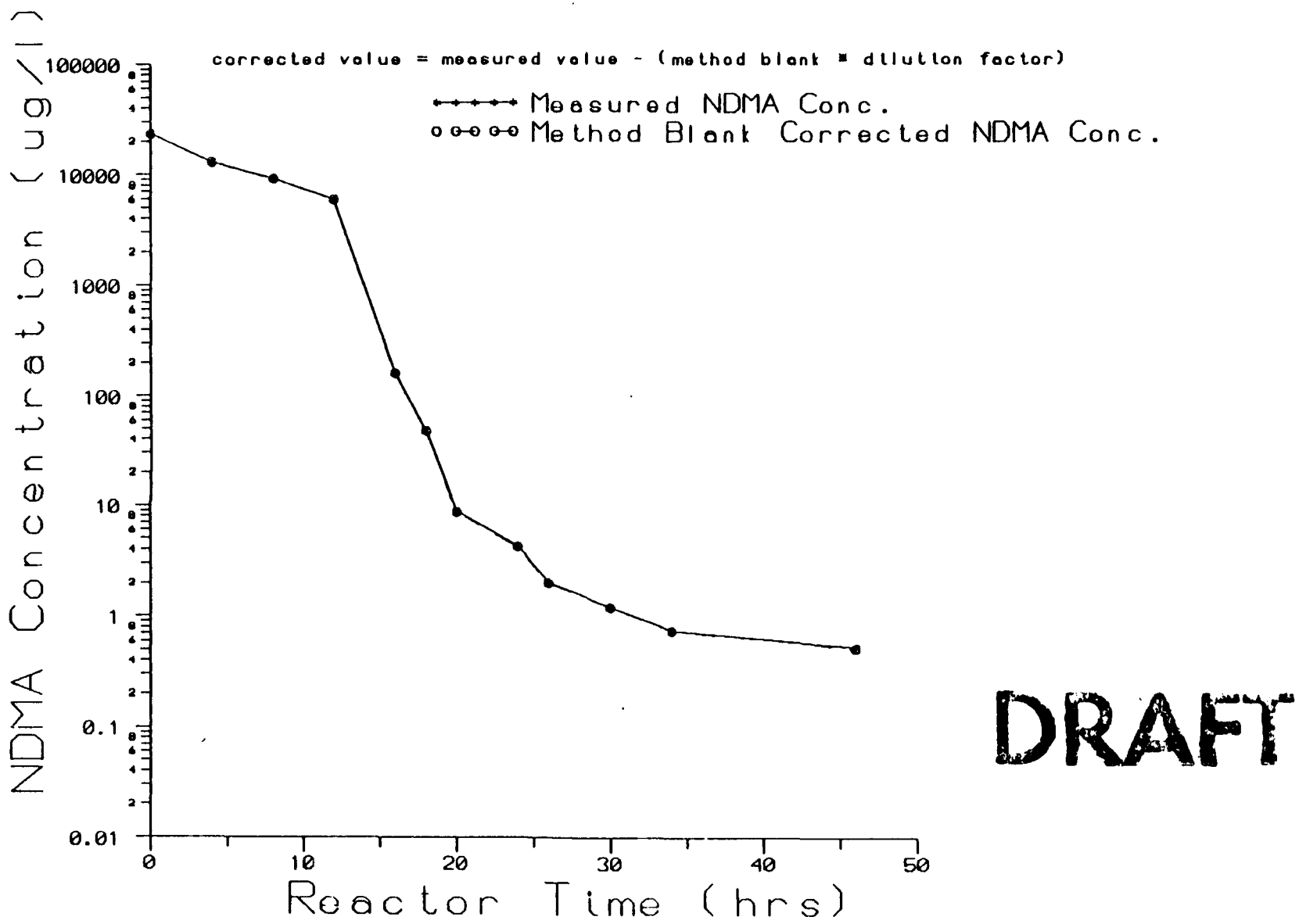

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Figure 7.10

BLANK-CORRECTED CHEMICAL CHARACTERIZATION CURVES FOR NDMA IN BATCH 4

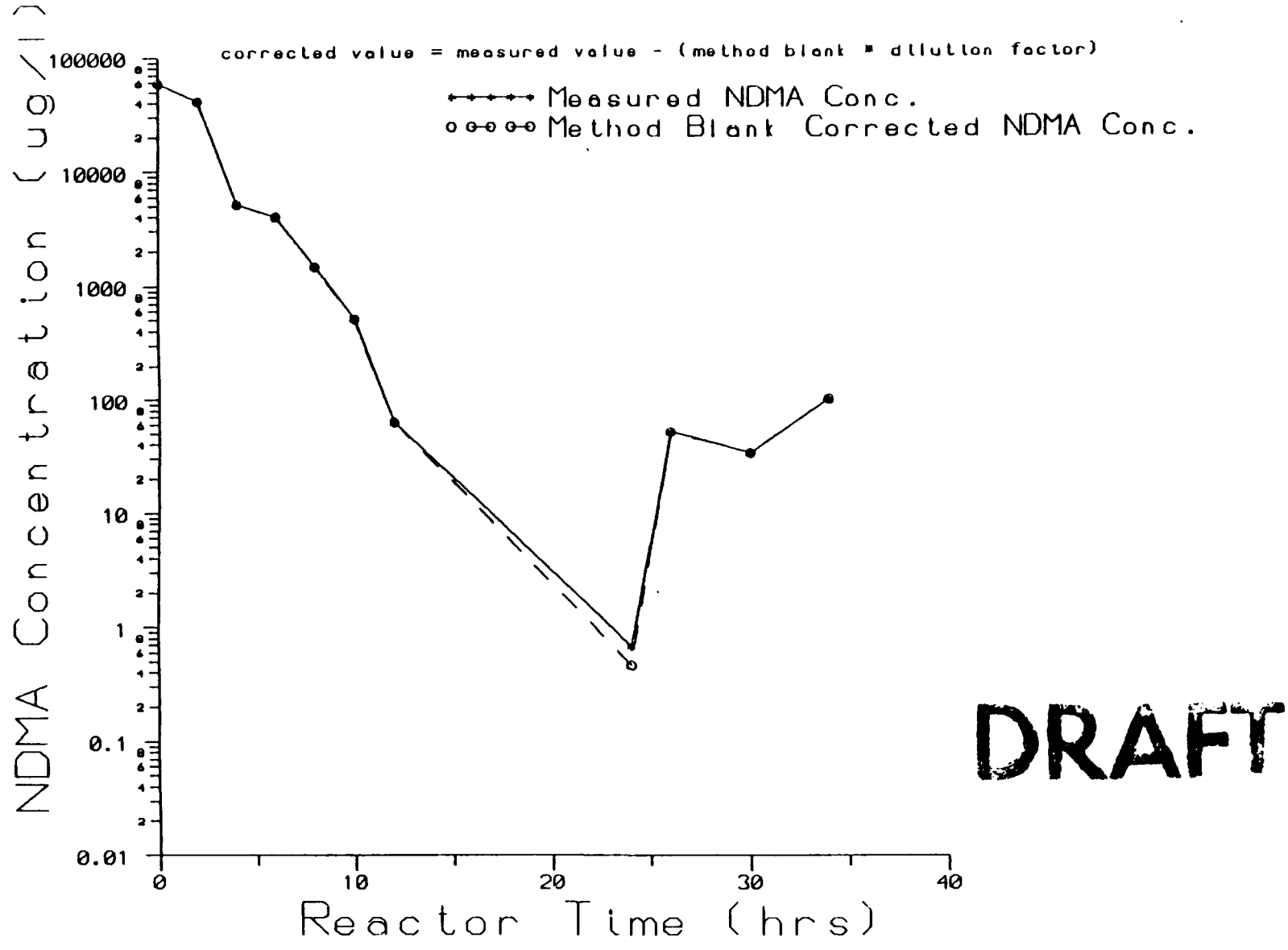

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Figure 7.11

BLANK-CORRECTED CHEMICAL CHARACTERIZATION CURVES FOR NDMA IN BATCH 5

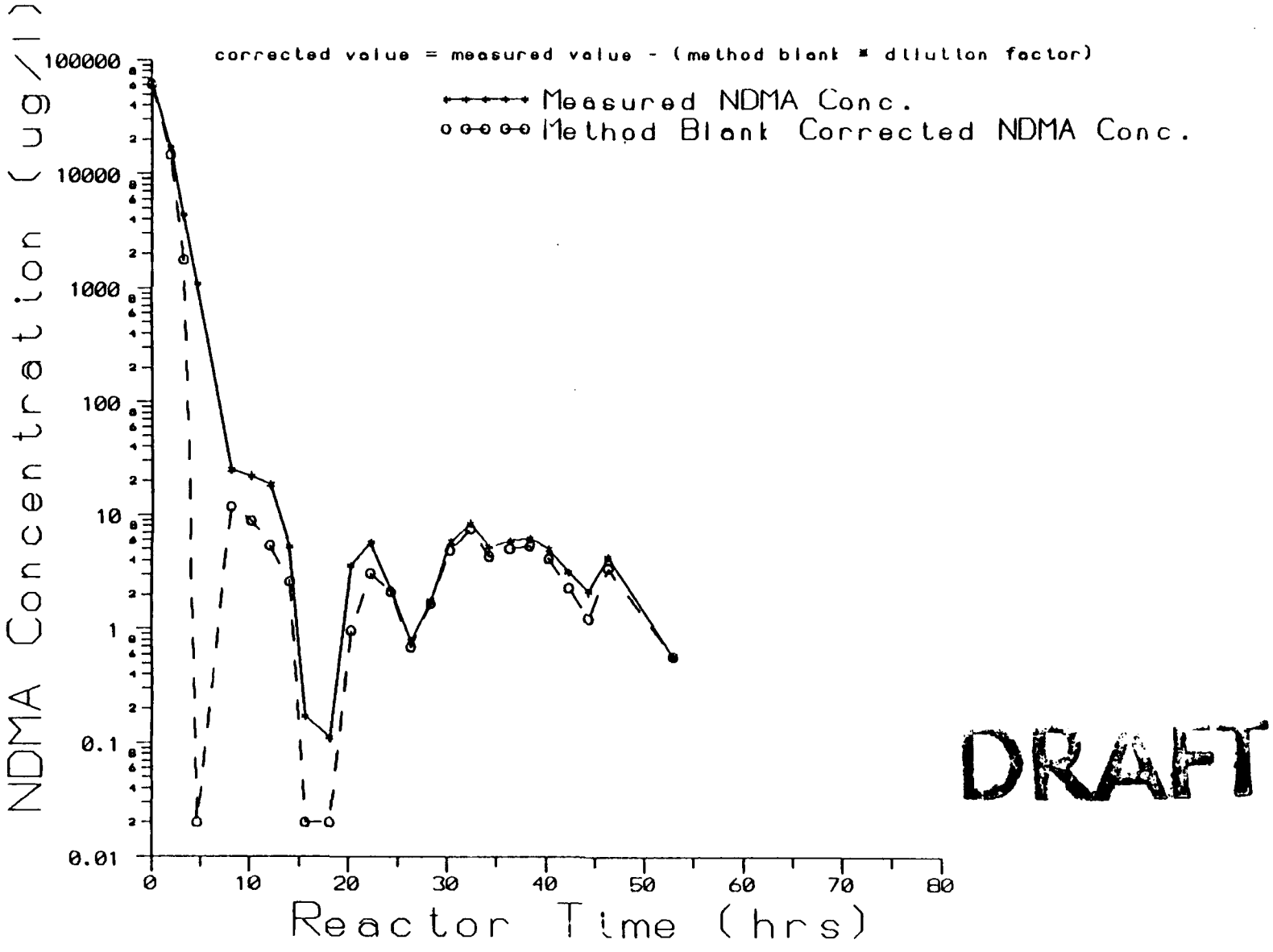

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Figure 7.12

BLANK-CORRECTED CHEMICAL CHARACTERIZATION CURVES FOR NDMA IN BATCH 9

laboratory audits as a concern. Subsequently, blank studies were conducted to isolate and eliminate the sources of cross-contamination. Ventilation and procedural modifications were implemented subsequent to the completion of the Phase I analytical program to eliminate the previously observed NDMA method blank contamination concern.

Overall, the results of the QA/QC program revealed that the reported analytical results were adequate, as qualified in this review, to depict the performance of the UV/chemical oxidation treatment system for removal of the hydrazine fuel compounds and NDMA. External and internal QC sample results coupled with the results of laboratory audits indicate that the analytical results presented in this report satisfy program requirements for precision, accuracy, representativeness, completeness, and comparability.

8.0 SUMMARY

Phase I of the HBSF IRA included analytical methods development and laboratory certification, bench/pilot-scale testing of UV/chemical oxidation treatment systems, full-scale startup testing, and air monitoring during startup testing. The following sections summarize these Phase I activities.

8.1 ANALYTICAL METHODS DEVELOPMENT/LABORATORY CERTIFICATION

Methods were successfully developed and certified in accordance with the PMRMA laboratory certification program for NDMA, hydrazine, MMH, and UDMH. The levels of concentration to which CRLs were obtained are reported in Table 5.1. The CRLs are adequate to achieve the action level specified in the final Decision Document for UDMH (25 μg/l) and to exceed the Decision Document action level of 20 μg/l for MMH. A technology-based action level was established for hydrazine on the basis of analytical method development and method certification of hydrazine in wastewater at a CRL of 9.9 μg/l. A technology-based action level was established for NDMA at 5 μg/l on the basis of treatment results demonstrated in the startup testing program.

8.2 BENCH/PILOT-SCALE TESTING PROGRAM

Bench- and pilot-scale testing were performed at the manufacturing facilities of qualified vendors of UV/chemical oxidation systems to evaluate whether the currently available technology is capable of treating the hydrazine wastewater stored at the HBSF to the action levels identified for this IRA. In general, the results from the bench/pilot-scale testing program indicated that the hydrazine fuel compounds could be reduced to below MRLs and NDMA could be reduced to less than 0.2 μg/l. These removal results were judged adequate for the purpose of selecting a vendor to conduct full-scale startup testing. Based on performance results in conjunction with other evaluation criteria, the UV/chemical oxidation system manufactured by PSI was selected for use in the full-scale startup testing program.

8.3 FULL-SCALE STARTUP TESTING PROGRAM

Various operating procedures and adjustments involving pretreatment for iron removal, pH, UV intensity, hydrogen peroxide concentration, and treatment time were tested and evaluated during full-scale startup testing of the UV/chemical oxidation treatment system. Treatment of nine batches was performed. The following were observed during the full-scale startup testing program:

- Pretreatment - Preoxidation with hydrogen peroxide did not enhance iron precipitation and may have contributed to an increase in influent NDMA concentrations when used. Polymer addition appeared to enhance removal of iron from the hydrazine wastewater.

- pH monitoring and control - Control of pH is necessary for removal of both the hydrazine fuel compounds and NDMA. Increasing wastewater pH increases the rate of oxidation of hydrazine, UDMH, and MMH. The pH can be monitored as an indicator of the hydrazine fuel compound concentration in the wastewater during the initial stage of a batch when the hydrazine fuel compounds are expected to be destroyed. The rate of hydrazine fuel compound destruction can be evaluated by monitoring pH in conjunction with ORP.

  After the hydrazine fuel compounds are reduced, it is important to decrease the pH of the batch solution to a level below 2.0 pH units to effect reduction of NDMA.

- ORP - ORP can also be monitored as an indicator of the concentration of the hydrazine fuel compounds in the wastewater.

- UV irradiation - UV light acts as a catalyst and reduces the time required for destruction of hydrazine fuel compounds and NDMA. The presence of UV light enhances the overall destruction of NDMA and, when combined with acidic conditions, is the dominating process factor in the destruction of NDMA.

- Hydrogen peroxide concentration - Maintenance of a hydrogen peroxide concentration of approximately 1000 mg/l during the initial stage of a batch when the hydrazine fuel compounds are expected to be destroyed appeared to be optimal to effect hydrazine fuel compound reduction. During the second stage of a batch when the NDMA is expected to be reduced, high levels of hydrogen peroxide cause utilization of the UV radiation in decomposing hydrogen peroxide to the OH radical, thereby limiting available photonic energy required to destroy NDMA.

- Treatment time - Wastewater influent concentration of the hydrazine fuel compounds and NDMA affects treatment time (i.e., the higher the influent concentration of these compounds, the longer the treatment time required for reduction of the compounds).

8.4 AIR MONITORING

An air-monitoring program was conducted during full-scale startup testing at the WWTF to monitor and evaluate the integrity of the UV/chemical oxidation treatment system and to monitor

personnel during operation and maintenance of the facility. Several methods for evaluating concentrations of hydrazine, MMH, UDMH, NDMA, and VOCs in air were utilized.

Results of the monitoring program indicate that concentrations of the hydrazine fuel compounds are well below regulatory and recommended limits. Because low concentrations of NDMA were consistently detected, supplied air was used by operations personnel during full-scale startup testing.

9.0 LIST OF ACRONYMS AND ABBREVIATIONS

µg/l	microgram per liter
ARARs	applicable or relevant and appropriate requirements
Army	U.S. Department of the Army
ASME	American Society of Mechanical Engineers
BTU	British thermal unit
CEEDO	Civil and Environmental Engineering Development Office
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CH	chiller
CPVC	chlorinated polyvinyl chloride
CRL	Certified Reporting Limit
CWTS	CERCLA wastewater treatment system
DataChem	DataChem Laboratories
DIMP	diisopropylmethylphosphonate
DBCP	dibromochloropropane
DCPD	dicyclopentadiene
DHHS	U.S. Department of Health and Human Services
DMMP	dimethylmethylphosphonate
DOI	U.S. Department of the Interior
DOJ	U.S. Department of Justice
DOT	U.S. Department of Transportation
DSA	duplicate sample agreement
Ebasco	Ebasco Services Incorporated
ECD	electron capture detector
EPA	U.S. Environmental Protection Agency
ES	Engineering-Science
°F	degrees Fahrenheit

FFA	Federal Facility Agreement
GAC	granular activated carbon
GC/ECD	gas chromotography/electron capture detector
GC/MS	gas chromotography/mass spectrometry
GC/NPD	gas chromotography/nitrogen phosphorus detector
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HBSF	Hydrazine Blending and Storage Facility
HDPE	high density polyethylene
I.D.	identification number
IITRI	Illinois Institute of Technology Research Institute
IRA	interim response action
IRA H	RMA IRA Task H for HBSF, Phase I
IRDMS	Installation Restoration Data Management System
mg/l	milligram per liter
MDL	method detection limit
MMH	monomethyl hydrazine
MRL	method reporting limit
MS	matrix spike
MSD	matrix spike duplicate
mv	millivolts
MX	mixer
NDMA	n-nitrosodimethylamine
nm	nanometers
NPDES	National Pollutant Discharge Elimination System

OH	hydroxyl radical
ORP	oxidation/reduction potential
OSHA	U.S. Occupational Safety and Health Administration
P	pump
PEL	permissible exposure level
PID	photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PSI	Peroxidation Systems, Inc.
psig	pounds per square inch gauge
QA	quality assurance
QC	quality control
R	reactor
RMA	Rocky Mountain Arsenal
STP	Sanitary Wastewater Treatment Plant
T	tank
TDH	total dynamic head
TWA	time-weighted average
UDMH	unsymmetrical dimethyl hydrazine
USAF	U.S. Air Force
UV	ultraviolet
VOC	volatile organic compound
W/V	weight/volume
WES	U.S. Army Corps of Engineers Waterways Experiment Station
WWTF	Wastewater Treatment Facility

10.0 REFERENCES

Civil and Environmental Engineering Development Office (CEEDO), 1978, Sierka, Raymond and Cowen, William, The Ozone Oxidation of Hydrazine Fuels: CEEDO-TR-78-43, September.

Code of Federal Regulations, 1990, 29 CFR 1910.1016.

Ebasco Services Incorporated, 1988, Final Decision Document for the Interim Response Action at the Rocky Mountain Arsenal Hydrazine Blending and Storage Facility, October.

Encyclopedia of Chemical Technology (ECT), 1978a, N-Nitrosamine: John Wiley and Sons, v. 15, p. 988-996.

Encyclopedia of Chemical Technology (ECT), 1978b, Hydrazine and its Derivatives: John Wiley and Sons, v. 12, p. 754-771.

Engineering-Science, 1988, A Method of Analysis for Hydrazine Compounds, Final Report, February.

Federal Facility Agreement, Docket No. CERCLA VIII-89-13.

Harding Lawson Associates (HLA), 1991, Draft Final Implementation Document for Decommissioning (Phase I), HBSF IRA Implementation, January 7.

Harding Lawson Associates (HLA), 1989a, Final Quality Assurance Program Plan, HBSF IRA Implementation, August 30.

Harding Lawson Associates (HLA), 1989b, Final Sampling Design Plan, HBSF IRA Implementation, August 30.

Harding Lawson Associates (HLA), 1989c, Final Task Plan, HBSF IRA Implementation, August 30.

IIT Research Institute (IITRI), 1988a, Ozonation of Wastewater Containing Hydrazine Fuels, Task 3: System Analysis and Process Design: Draft Task Report, IITRI Project C06631, October.

IIT Research Institute (IITRI), 1988b, Specification for Tungsten Catalyst: Designator TK102 Drawing No. C06631-A/C-102, February 7.

IIT Research Institute (IITRI), 1987, Treatment of the Hydrazine Water from Rocky Mountain Arsenal: Final Report No. C06658-2, July.

IIT Research Institute (IITRI), 1986, Neutralization of Hydrazine Fuels Using Selected Oxidation Processes: Final Report Task 4, Report No. IITRI-C06567C004-TR, March.

Jody, B.J., and others, 1983, Ozonation of Hydrazine Fuels and Their Associated Impurities, Proc. Environmental Fate of Hydrazine Fuels in Aqueous and Soil Environments, p. 202-215.

Occupational Safety and Health Administration (OSHA), 1990, 29 Code of Federal Regulations (CFR) Part 1910.1000 - Air Contaminants.

Program Manager for Rocky Mountain Arsenal, 1989, Rocky Mountain Arsenal Chemical Quality Assurance Plan, Version 1.0, July.

U.S. Environmental Protection Agency, 1989, Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A), Interim Final, December.

Waterways Experiment Station, Army Corps of Engineers, 1989, CERCLA Wastewater Treatment System Needs Assessment and Processes Treatability Study: PMRMA Draft Final Report, June.

Appendix A

ANALYTICAL DATA

WASTEWATER CHARACTERIZATION

Table A1: Hydrazine Blending and Storage Facility Waste Tank US-3 Chemical Characterization[1]
(Page 1 of 4)

Sampling Depth (in feet)	4.5	9.5	14.5
Hydrazine Fuel Compounds / NDMA			
Hydrazine	22000	60000	27000
Monomethyl hydrazine	94000	90000	50000
Unsymmetrical dimethyl hydrazine	69000	110000	53000
n-Nitrosodimethylamine	610	790	500
Volatile Organics			
Acetone	< 440	< 550	50.7
Acrolein	< 400	< 500	< 19.5
Acrylonitrile	< 168	< 210	< 8.43
Benzene	92.0	112	53.0
Bromodichloromethane	< 36.0	< 45.0	< 1.82
Bromoform	< 106	< 133	< 5.25
Bromomethane	< 136	< 170	< 6.81
Carbon disulfide	< 144	< 180	< 7.20
Carbon tetrachloride	< 24.0	< 30.0	< 1.19
Chlorobenzene	< 10.6	< 13.3	41.6
Chloroethane	< 320	< 400	2000
Chloroform	3200	4750	3400
Chloromethane	< 108	< 135	45.3
Dibromochloromethane	< 64.0	< 80.0	< 3.23
Dibromochloropropane	< .130	< .130	< .130
1,2-Dichloroethane	66.0	< 35.0	143
1,1-Dichloroethane	108	190	570
1,1-Dichloroethene	< 240	< 300	13.1
1,2-Dichloropropane	< 26.0	37.5	89.1
Dicyclopentadiene	< 9.31	< 9.31	< 9.31
Dimethyl disulfide	9.65	14.2	4.87
Ethylbenzene	< 22.0	< 27.5	< 1.09
2-Hexanone	< 220	< 275	< 11.2
Methylethyl ketone	< 220	< 275	27.2
Methylene chloride	2800	4000	13000
Methylisobutyl ketone	< 12.9	< 12.9	< 11.2
o,p-Xylene	< 22.0	< 27.5	1.84
Styrene	< 11.2	< 14.0	< .560
1,1,2,2-Tetrachloroethane	< 166	< 208	< 8.25
Tetrachloroethene	< 20.0	< 25.0	2.60
Toluene	< 26.0	< 32.5	5.09
1,1,1-Trichloroethane	< 17.8	< 22.3	< .890
1,1,2-Trichloroethane	< 74.0	< 92.5	< 3.72
Trichloroethene	< 7.80	< 9.75	5.16
Vinyl acetate	134	< 158	< 6.26
Vinyl chloride	< 110	< 138	78.3
cis-1,3-Dichloropropylene	< 92.0	< 115	< 4.61
trans-1,2-Dichloroethylene	< 66.0	< 82.5	< 3.31
trans-1,3-Dichloropropene	< 38.0	< 47.5	< 1.88

Table A1: (Page 2 of 4)

Sampling Depth (in feet)	4.5	9.5	14.5
Semivolatiles			
Acenaphthene	< 1.91	< 1.91	< 1.91
Acenaphthylene	< 1.37	< 1.37	< 1.37
Aniline	1200	1460	1260
Anthracene	< 1.07	< 1.07	< 1.07
Atrazine	33.1	44.0	41.3
Benzidine	< 12.5	< 12.5	< 12.5
Benzo [A] anthracene	< .880	< .880	< .880
Benzo [A] pyrene	< 2.59	< 2.59	< 2.59
Benzo [B] fluoranthene	< 1.90	< 1.90	< 1.90
Benzo [G,H,I] perylene	< 1.05	< 1.05	< 1.05
Benzo [K] fluoranthene	< 2.37	< 2.37	< 2.37
Benzoic acid	< 6.23	< 6.23	< 6.23
Benzothiazole	2.74	2.47	2.74
Benzyl alcohol	< 1.28	< 1.28	< 1.28
4-Bromophenylphenyl ether	< .990	< .990	< .990
Butylbenzyl phthalate	< 2.06	< 2.06	< 2.06
4-Chloroaniline	< 1.68	< 1.68	< 1.68
2-Chloronaphthalene	< 1.27	< 1.27	< 1.27
2-Chlorophenol	< 1.12	< 1.12	< 1.12
4-Chlorophenylmethyl sulfide	< 1.08	< 1.08	< 1.08
4-Chlorophenylmethyl sulfone	< 2.24	< 2.24	< 2.24
4-Chlorophenylmethyl sulfoxide	< 1.98	< 1.98	< 1.98
4-Chlorophenylphenyl ether	< 1.20	< 1.20	< 1.20
Chrysene	< 1.38	< 1.38	< 1.38
di-n-Butyl phthalate	< 1.50	< 1.50	< 1.50
di-n-Octyl phthalate	< 1.01	< 1.01	< 1.01
Dibenz [A,H] anthracene	< .900	< .900	< .900
Dibenzofuran	< 1.03	< 1.03	< 1.03
2,3,7,8-Dibenzo-p-dioxin	< .001	< .001	< .001
1,3-Dichlorobenzene	< 3.18	< 3.18	< 3.18
1,4-Dichlorobenzene	< 3.52	< 3.52	< 3.52
1,2-Dichlorobenzene	< 3.86	< 3.86	< 3.86
3,3'-Dichlorobenzidine	< 1.60	< 1.60	< 1.60
2,4-Dichlorophenol	< 1.42	< 1.42	< 1.42
Diethyl phthalate	< 2.36	< 2.36	< 2.36
Diisopropyl methylphosphonate	< 10.1	< 10.1	< 10.1
Dimethyl phthalate	< 2.62	< 2.62	< 2.62
Dimethylmethyl phosphonate	< 16.3	< 16.3	< 16.3
2,4-Dimethylphenol	< 3.43	< 3.43	< 3.43
4,6-Dinitro-2-cresol	< 2.40	< 2.40	< 2.40
2,4-Dinitrophenol	< 3.04	< 3.04	< 3.04
2,4-Dinitrotoluene	< 1.13	< 1.13	< 1.13
2,6-Dinitrotoluene	< 1.65	< 1.65	< 1.65
1,2-Diphenylhydrazine	< 5.00	< 5.00	< 5.00
Dithiane	< 3.34	< 3.34	< 3.34
Fluoranthene	< 1.62	< 1.62	< 1.62
Fluorene	< 1.54	< 1.54	< 1.54
Hexachlorobenzene	< 1.37	< 1.37	< 1.37
Hexachlorobutadiene	< 3.54	< 3.54	< 3.54

Table A1: (Page 3 of 4)

Sampling Depth (in feet)	4.5	9.5	14.5
Hexachlorocyclopentadiene	< 2.05	< 2.05	< 2.05
Hexachloroethane	< 4.46	< 4.46	< 4.46
Indeno [1,2,3-C,D] pyrene	< 1.36	< 1.36	< 1.36
Isophorone	< .910	< .910	< .910
Malathion	< .373	< .373	< .373
3-Methyl-4-chlorophenol	< 1.61	< 1.61	< 1.61
2-Methylnaphthalene	< 3.16	< 3.16	< 3.16
2-Methylphenol	< 1.28	< 1.28	< 1.28
4-Methylphenol	< 3.89	< 3.89	< 3.89
n-Nitrosodiphenylamine	< 1.08	< 1.08	< 1.08
Naphthalene	8.18	8.78	14.2
2-Nitroaniline	< 1.07	< 1.07	< 1.07
3-Nitroaniline	< 1.78	< 1.78	< 1.78
4-Nitroaniline	< 2.72	< 2.72	< 2.72
Nitrobenzene	< .940	< .940	< .940
2-Nitrophenol	< .720	< .720	< .720
4-Nitrophenol	< 2.61	< 2.61	< 2.61
Nitroso di-n-propylamine	< 1.20	< 1.20	< 1.20
1,4-Oxathiane	< 1.35	< 1.35	< 1.35
Parathion	< .647	< .647	< .647
Pentachlorophenol	< 2.20	< 2.20	< 2.20
Phenanthrene	< .960	< .960	1.24
Phenol	< 2.30	< 2.30	< 2.30
Pyrene	< 1.02	< 1.02	< 1.02
Supona	< .787	< .787	< .787
1,2,4-Trichlorobenzene	< 2.97	< 2.97	< 2.97
2,4,5-Trichlorophenol	< 1.38	< 1.38	< 1.38
2,4,6-Trichlorophenol	< 1.47	< 1.47	< 1.47
Vapona	< .384	19.1	< .384
bis(2-Chloroethoxy) methane	< 1.18	< 1.18	< 1.18
bis(2-Chloroethyl) ether	< 1.01	< 1.01	< 1.01
bis(2-Chloroisopropyl) ether	< 1.67	< 1.67	< 1.67
bis(2-Ethylhexyl) phthalate	< 1.98	2.00	< 1.98
Pesticides			
Aldrin	< .050	< .050	.252
Alpha BHC	< .050	< .050	< .050
Alpha endosulfan	< .050	< .050	< .050
Beta BHC	< .050	< .050	< .050
Beta endosulfan	< .100	< .100	< .100
Chlordane	< .500	< .500	< .500
DDD	< .100	< .100	< .100
DDE	< .100	< .100	< .100
DDT	< .100	< .100	< .100
Delta BHC	< .050	< .050	< .050
Dieldrin	.139	.125	.101
Endrin	< .100	< .100	< .100
Endrin aldehyde	< .500	< .500	< .500
Endrin sulfate	< .100	< .100	< .100
Heptachlor	< .050	< .050	< .050

Table A1: (Page 4 of 4)

Sampling Depth (in feet)	4.5	9.5	14.5
Heptachlor epoxide	< .050	< .050	< .050
Lindane	< .050	< .050	.255
Methoxychlor	< .500	< .500	< .500
PCB 1016	< .500	< .500	< .500
PCB 1221	< .500	< .500	< .500
PCB 1232	< .500	< .500	< .500
PCB 1242	< .500	< .500	< .500
PCB 1254	< 1.00	< 1.00	< 1.00
PCB 1260	< 1.00	< 1.00	< 1.00
Toxaphene	< 1.00	< 1.00	< 1.00
Metals			
Arsenic	64.2	61.8	43.1
Cadmium	< .500	< .500	< .500
Chromium	6.18	5.22	< 4.30
Copper	7.48	< 1.70	< 1.70
Iron	48.0	66.8	810000
Lead	< 5.00	< 5.00	< 5.00
Mercury	.760	.868	.738
Selenium	< 2.50	< 2.50	< 2.50
Silver	< .200	< .200	.462
Zinc	28.9	27.7	< 2.00

[1] concentrations in micrograms per liter (μg/l)

BHC = hexachlorocyclohexane
DDD = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethane
DDE = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethene
DDT = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1,1-trichloroethane
N/A = no analysis available
NDMA = n-nitrosodimethylamine
PCB = polychlorinated biphenyl
< = compound not detected at or above method detection limit

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Table A2: Hydrazine Blending and Storage Facility Waste Tank US-4 Chemical Characterization[1]
(Page 1 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Hydrazine Fuel Compounds / NDMA			
Hydrazine	790000	1000000	1100000
Monomethyl hydrazine	140000	320000	180000
Unsymmetrical dimethyl hydrazine	1100000	810000	790000
n-Nitrosodimethylamine	60.0	120	53.0
Volatile Organics			
Acetone	< 22.2	32.0	23.8
Acrolein	< 19.5	< 10.0	< 19.5
Acrylonitrile	< 8.43	< 10.0	< 8.43
Benzene	2.66	< 5.00	2.41
Bromodichloromethane	< 1.82	< 5.00	< 1.82
Bromoform	< 5.25	< 5.00	< 5.25
Bromomethane	< 6.81	< 10.0	< 6.81
Carbon disulfide	< 7.20	< 5.00	< 7.20
Carbon tetrachloride	< 1.19	< 5.00	< 1.19
Chlorobenzene	< .530	< 5.00	< .530
Chloroethane	< 16.2	< 10.0	< 16.2
Chloroform	96.6	106	102
Chloromethane	25.6	< 10.0	< 5.43
Dibromochloromethane	< 3.23	< 5.00	< 3.23
Dibromochloropropane	< .130	< .130	< .130
1,2-Dichloroethane	1.67	< 5.00	1.66
1,1-Dichloroethane	3.66	< 5.00	3.89
1,1-Dichloroethene	< 12.4	< 5.00	< 12.4
1,2-Dichloropropane	< 1.34	< 5.00	< 1.34
Dicyclopentadiene	< 9.31	< 9.31	< 9.31
Dimethyl disulfide	57.0	53.0	61.0
Ethylbenzene	< 1.09	< 5.00	< 1.09
2-Hexanone	< 11.2	< 10.0	< 11.2
Methylethyl ketone	< 10.9	< 10.0	< 10.9
Methylene chloride	61.0	110	89.6
Methylisobutyl ketone	< 11.2	< 10.0	< 11.2
o,p-Xylene	< 1.10	< 5.00	< 1.10
Styrene	< .560	< 5.00	< .560
1,1,2,2-Tetrachloroethane	< 8.25	< 5.00	< 8.25
Tetrachloroethene	< 1.01	< 5.00	< 1.01
Toluene	< 1.29	< 5.00	< 1.29
1,1,1-Trichloroethane	< .890	< 5.00	< .890
1,1,2-Trichloroethane	< 3.72	< 5.00	< 3.72
Trichloroethene	< .390	< 5.00	< .390
Vinyl acetate	< 6.26	< 10.0	< 6.26
Vinyl chloride	< 5.51	< 10.0	< 5.51
cis-1,3-Dichloropropylene	< 4.61	< 5.00	< 4.61
trans-1,2-Dichloroethylene	< 3.31	< 5.00	< 3.31
trans-1,3-Dichloropropene	< 1.88	< 5.00	< 1.88

Table A2: (Page 2 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Semivolatiles			
Acenaphthene	< 1.91	< .385	< 1.91
Acenaphthylene	< 1.37	< .343	< 1.37
Aniline	1500	N/A	6400
Anthracene	< 1.07	< .634	< 1.07
Atrazine	4.92	4.85	5.50
Benzidine	< 12.5	N/A	< 12.5
Benzo [A] anthracene	< .880	< .302	< .880
Benzo [A] pyrene	< 2.59	< .291	< 2.59
Benzo [B] fluoranthene	< 1.90	< .842	< 1.90
Benzo [G,H,I] perylene	< 1.05	< 1.25	< 1.05
Benzo [K] fluoranthene	< 2.37	< 1.73	< 2.37
Benzoic acid	< 6.23	< 3.32	< 6.23
Benzothiazole	3.25	14.9	2.97
Benzyl alcohol	< 1.28	< .728	< 1.28
4-Bromophenylphenyl ether	< .990	< .603	< .990
Butylbenzyl phthalate	< 2.06	< 2.20	< 2.06
4-Chloroaniline	2.94	< .707	2.88
2-Chloronaphthalene	< 1.27	< .478	< 1.27
2-Chlorophenol	< 1.12	< .281	< 1.12
4-Chlorophenylmethyl sulfide	< 1.08	< 1.08	< 1.08
4-Chlorophenylmethyl sulfone	< 2.24	< 2.24	< 2.24
4-Chlorophenylmethyl sulfoxide	< 1.98	< 1.98	< 1.98
4-Chlorophenylphenyl ether	< 1.20	< .832	< 1.20
Chrysene	< 1.38	< 3.21	< 1.38
di-n-Butyl phthalate	< 1.50	< 1.80	< 1.50
di-n-Octyl phthalate	< 1.01	< 5.13	< 1.01
Dibenz [A,H] anthracene	< .900	< 1.70	< .900
Dibenzofuran	< 1.03	< .354	< 1.03
2,3,7,8-Dibenzo-p-dioxin	< .001	< .001	< .001
1,3-Dichlorobenzene	< 3.18	< .104	< 3.18
1,4-Dichlorobenzene	< 3.52	< .239	< 3.52
1,2-Dichlorobenzene	< 3.86	< .416	< 3.86
3,3'-Dichlorobenzidine	< 1.60	< 4.04	< 1.60
2,4-Dichlorophenol	< 1.42	< .364	< 1.42
Diethyl phthalate	< 2.36	< 1.76	< 2.36
Diisopropyl methylphosphonate	< 10.1	< 10.1	< 10.1
Dimethyl phthalate	< 2.62	< .874	< 2.62
Dimethylmethyl phosphonate	< 16.3	< 16.3	< 16.3
2,4-Dimethylphenol	< 3.43	< .281	< 3.43
4,6-Dinitro-2-cresol	< 2.40	< 3.15	< 2.40
2,4-Dinitrophenol	< 3.04	< 3.55	< 3.04
2,4-Dinitrotoluene	< 1.13	< 1.93	< 1.13
2,6-Dinitrotoluene	< 1.65	< 2.55	< 1.65
1,2-Diphenylhydrazine	< 5.00	N/A	< 5.00
Dithiane	< 3.34	< 3.34	< 3.34
Fluoranthene	< 1.62	< 1.44	< 1.62
Fluorene	< 1.54	< .905	< 1.54
Hexachlorobenzene	< 1.37	< .707	< 1.37
Hexachlorobutadiene	< 3.54	< .551	< 3.54

Table A2: (Page 3 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Hexachlorocyclopentadiene	< 2.05	< .083	< 2.05
Hexachloroethane	< 4.46	< .291	< 4.46
Indeno [1,2,3-C,D] pyrene	< 1.36	< 1.67	< 1.36
Isophorone	< .910	< .374	< .910
Malathion	< .373	< .373	< .373
3-Methyl-4-chlorophenol	< 1.61	< .988	< 1.61
2-Methylnaphthalene	< 3.16	< .894	< 3.16
2-Methylphenol	< 1.28	< .832	< 1.28
4-Methylphenol	< 3.89	< .884	< 3.89
n-Nitrosodiphenylamine	< 1.08	< .551	< 1.08
Naphthalene	< 2.96	< .270	< 2.96
2-Nitroaniline	< 1.07	< 2.38	< 1.07
3-Nitroaniline	< 1.78	< 3.17	< 1.78
4-Nitroaniline	< 2.72	< 3.99	< 2.72
Nitrobenzene	< .940	< 1.14	< .940
2-Nitrophenol	< .720	< 1.86	< .720
4-Nitrophenol	< 2.61	< 3.90	< 2.61
Nitroso di-n-propylamine	< 1.20	< 1.42	< 1.20
1,4-Oxathiane	< 1.35	< 1.35	< 1.35
Parathion	< .647	< .647	< .647
Pentachlorophenol	< 2.20	< 1.89	< 2.20
Phenanthrene	< .960	< .478	< .960
Phenol	< 2.30	< 1.06	< 2.30
Pyrene	< 1.02	< 1.73	< 1.02
Supona	< .787	< .787	< .787
1,2,4-Trichlorobenzene	< 2.97	< .541	< 2.97
2,4,5-Trichlorophenol	< 1.38	< .354	< 1.38
2,4,6-Trichlorophenol	< 1.47	< .957	< 1.47
Vapona	< .384	< .384	< .384
bis(2-Chloroethoxy) methane	< 1.18	< .499	< 1.18
bis(2-Chloroethyl) ether	< 1.01	< .291	< 1.01
bis(2-Chloroisopropyl) ether	< 1.67	< 1.09	< 1.67
bis(2-Ethylhexyl) phthalate	< 1.98	< 3.26	11.0
Pesticides			
Aldrin	< .050	< .155	< .050
Alpha BHC	< .050	< .155	< .050
Alpha endosulfan	< .050	N/A	< .050
Beta BHC	< .050	< .155	< .050
Beta endosulfan	< .100	< .315	< .100
Chlordane	< .500	< 1.55	< .500
DDD	< .100	< .315	< .100
DDE	< .100	< .315	< .100
DDT	< .100	< .315	< .100
Delta BHC	< .050	< .155	< .050
Dieldrin	< .100	< .315	< .100
Endrin	< .100	< .315	< .100
Endrin aldehyde	< .500	< 1.55	< .500
Endrin sulfate	< .100	< .315	< .100
Heptachlor	< .050	N/A	< .050

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Table A2: (Page 4 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Heptachlor epoxide	< .050	< .155	< .050
Lindane	< .050	N/A	< .050
Methoxychlor	< .500	< 1.55	< .500
PCB 1016	< .500	< 1.55	< .500
PCB 1221	< .500	< 1.55	< .500
PCB 1232	< .500	< 1.55	< .500
PCB 1242	< .500	< 1.55	< .500
PCB 1254	< 1.00	< 3.15	< 1.00
PCB 1260	< 1.00	< 3.15	< 1.00
Toxaphene	< 1.00	< 3.15	< 1.00
Metals			
Arsenic	18.8	16.1	20.4
Cadmium	< .500	< .200	< .500
Chromium	6.62	< 22.4	6.95
Copper	< 1.70	< 10.0	< 1.70
Iron	6330	N/A	12100
Lead	< 5.00	< 2.00	< 5.00
Mercury	.241	.658	.327
Selenium	< 2.50	< 2.00	< 2.50
Silver	< .200	.224	< .200
Zinc	13.4	< 20.0	12.4

[1] concentrations in micrograms per liter (µg/l)

BHC = hexachlorocyclohexane
DDD = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethane
DDE = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethene
DDT = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1,1-trichloroethane
N/A = no analysis available
NDMA = n-nitrosodimethylamine
PCB = polychlorinated biphenyl
< = compound not detected at or above method detection limit

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Table A3: Hydrazine Blending and Storage Facility In-Ground Concrete Sump Chemical Characterization[1]
(Page 1 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Hydrazine Fuel Compounds / NDMA			
Hydrazine	2100	850	380
Monomethyl hydrazine	< 2500	< 2500	< 2500
Unsymmetrical dimethyl hydrazine	1600	350	85.0
n-Nitrosodimethylamine	4.40	5.80	1.40
Volatile Organics			
Acetone	< 22.2	< 22.2	< 440
Acrolein	< 19.5	< 19.5	< 400
Acrylonitrile	< 8.43	< 8.43	< 168
Benzene	< .830	< .830	< 16.6
Bromodichloromethane	< 1.82	< 1.82	< 36.0
Bromoform	< 5.25	< 5.25	< 106
Bromomethane	< 6.81	< 6.81	< 136
Carbon disulfide	< 7.20	< 7.20	< 144
Carbon tetrachloride	< 1.19	< 1.19	< 24.0
Chlorobenzene	< .530	< .530	< 10.6
Chloroethane	< 16.2	< 16.2	< 320
Chloroform	< 1.93	< 1.93	< 38.0
Chloromethane	< 5.43	< 5.43	< 108
Dibromochloromethane	< 3.23	< 3.23	< 64.0
Dibromochloropropane	< .130	< .130	< .130
1,2-Dichloroethane	< 1.41	< 1.41	< 28.0
1,1-Dichloroethane	< 1.53	< 1.53	< 30.0
1,1-Dichloroethene	< 12.4	< 12.4	< 240
1,2-Dichloropropane	< 1.34	< 1.34	< 26.0
Dicyclopentadiene	< 9.31	< 9.31	< 9.31
Dimethyl disulfide	< 1.16	< 1.16	< 1.16
Ethylbenzene	< 1.09	< 1.09	< 22.0
2-Hexanone	< 11.2	< 11.2	< 220
Methylethyl ketone	< 10.9	13.3	< 220
Methylene chloride	< 22.2	< 22.2	< 440
Methylisobutyl ketone	< 11.2	< 11.2	< 12.9
o,p-Xylene	< 1.10	< 1.10	< 22.0
Styrene	< .560	< .560	< 11.2
1,1,2,2-Tetrachloroethane	< 8.25	< 8.25	< 166
Tetrachloroethene	< 1.01	< 1.01	< 20.0
Toluene	98.8	115	680
1,1,1-Trichloroethane	< .890	< .890	< 17 8
1,1,2-Trichloroethane	< 3.72	< 3.72	< 74.0
Trichloroethene	< .390	< .390	< 7.80
Vinyl acetate	< 6.26	< 6.26	< 126
Vinyl chloride	< 5.51	< 5.51	< 110
cis-1,3-Dichloropropylene	< 4.61	< 4.61	< 92.0
trans-1,2-Dichloroethylene	< 3.31	< 3.31	< 66.0
trans-1,3-Dichloropropene	< 1.88	< 1.88	< 38.0

Table A3: (Page 2 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Semivolatiles			
Acenaphthene	< 1.91	< 1.91	< 1.91
Acenaphthylene	< 1.37	< 1.37	< 1.37
Aniline	< 1.60	< 1.60	< 1.60
Anthracene	< 1.07	< 1.07	< 1.07
Atrazine	150	10.5	8.86
Benzidine	< 12.5	< 12.5	< 12.5
Benzo [A] anthracene	< .880	< .880	< .880
Benzo [A] pyrene	< 2.59	< 2.59	< 2.59
Benzo [B] fluoranthene	< 1.90	< 1.90	< 1.90
Benzo [G,H,I] perylene	< 1.05	< 1.05	< 1.05
Benzo [K] fluoranthene	< 2.37	< 2.37	< 2.37
Benzoic acid	< 6.23	< 6.23	< 6.23
Benzothiazole	< 11.4	< 11.4	< 11.4
Benzyl alcohol	< 1.28	< 1.28	< 1.28
4-Bromophenylphenyl ether	< .990	< .990	< .990
Butylbenzyl phthalate	< 2.06	< 2.06	< 2.06
4-Chloroaniline	< 1.68	< 1.68	< 1.68
2-Chloronaphthalene	< 1.27	< 1.27	< 1.27
2-Chlorophenol	< 1.12	< 1.12	< 1.12
4-Chlorophenylmethyl sulfide	< 10.8	< 10.8	< 10.8
4-Chlorophenylmethyl sulfone	< 22.4	< 22.4	< 22.4
4-Chlorophenylmethyl sulfoxide	< 19.8	< 19.8	< 19.8
4-Chlorophenylphenyl ether	< 1.20	< 1.20	< 1.20
Chrysene	< 1.38	< 1.38	< 1.38
di-n-butyl phthalate	< 1.50	< 1.50	< 1.50
di-n-octyl phthalate	< 1.01	< 1.01	< 1.01
Dibenz [A,H] anthracene	< .900	< .900	< .900
Dibenzofuran	< 1.03	< 1.03	< 1.03
2,3,7,8-Dibenzo-p-dioxin	< .001	< .001	< .001
1,3-Dichlorobenzene	< 3.18	< 3.18	< 3.18
1,4-Dichlorobenzene	< 3.52	< 3.52	< 3.52
1,2-Dichlorobenzene	< 3.86	< 3.86	< 3.86
3,3'-Dichlorobenzidine	< 1.60	< 1.60	< 1.60
2,4-Dichlorophenol	< 1.42	< 1.42	< 1.42
Diethyl phthalate	< 2.36	< 2.36	< 2.36
Diisopropyl methylphosphonate	< 10.1	< 10.1	< 10.1
Dimethyl phthalate	< 2.62	< 2.62	< 2.62
Dimethylmethyl phosphonate	< 16.3	< 16.3	< 16.3
2,4-Dimethylphenol	< 3.43	< 3.43	< 3.43
4,6-Dinitro-2-cresol	< 2.40	< 2.40	< 2.40
2,4-Dinitrophenol	< 3.04	< 3.04	< 3.04
2,4-Dinitrotoluene	< 1.13	< 1.13	< 1.13
2,6-Dinitrotoluene	< 1.65	< 1.65	< 1.65
1,2-Diphenylhydrazine	< 5.00	< 5.00	< 5.00
Dithiane	< 33.4	< 33.4	< 33.4
Fluoranthene	< 1.62	< 1.62	< 1.62
Fluorene	< 1.54	< 1.54	< 1.54
Hexachlorobenzene	< 1.37	< 1.37	< 1.37
Hexachlorobutadiene	< 3.54	< 3.54	< 3.54

Table A3: (Page 3 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Hexachlorocyclopentadiene	< 2.05	< 2.05	< 2.05
Hexachloroethane	< 4.46	< 4.46	< 4.46
Indeno [1,2,3-C,D] pyrene	< 1.36	< 1.36	< 1.36
Isophorone	< .910	< .910	< .910
Malathion	< .373	.574	< .373
3-Methyl-4-chlorophenol	< 1.61	< 1.61	< 1.61
2-Methylnaphthalene	< 3.16	< 3.16	< 3.16
2-Methylphenol	< 1.28	< 1.28	< 1.28
4-Methylphenol	105	45.5	320
n-Nitrosodiphenylamine	< 1.08	< 1.08	< 1.08
Naphthalene	< 2.96	< 2.96	< 2.96
2-Nitroaniline	< 1.07	< 1.07	< 1.07
3-Nitroaniline	< 1.78	< 1.78	< 1.78
4-Nitroaniline	< 2.72	< 2.72	< 2.72
Nitrobenzene	< .940	< .940	< .940
2-Nitrophenol	< .720	< .720	< .720
4-Nitrophenol	< 2.61	< 2.61	< 2.61
Nitroso di-n-propylamine	< 1.20	< 1.20	< 1.20
1,4-Oxathiane	< 13.5	< 13.5	< 13.5
Parathion	< .647	< .647	< .647
Pentachlorophenol	< 2.20	< 2.20	< 2.20
Phenanthrene	< .960	< .960	< .960
Phenol	4.12	< 2.30	< 2.30
Pyrene	< 1.02	< 1.02	< 1.02
Supona	< .787	< .787	< .787
1,2,4-Trichlorobenzene	< 2.97	< 2.97	< 2.97
2,4,5-Trichlorophenol	< 1.38	< 1.38	< 1.38
2,4,6-Trichlorophenol	< 1.47	< 1.47	< 1.47
Vapona	< .384	< .384	< .384
bis(2-Chloroethoxy) methane	< 1.18	< 1.18	< 1.18
bis(2-Chloroethyl) ether	< 1.01	< 1.01	< 1.01
bis(2-Chloroisopropyl) ether	< 1.67	< 1.67	< 1.67
bis(2-Ethylhexyl) phthalate	< 1.98	< 1.98	2.14
Pesticides			
Aldrin	< .500	< .500	< .500
Alpha BHC	< .500	< .500	< .500
Alpha endosulfan	< .500	< .500	< .500
Beta BHC	< .500	< .500	< .500
Beta endosulfan	< .100	< .100	< .100
Chlordane	< 5.00	< 5.00	< 5.00
DDD	< .100	< .100	< .100
DDE	< 1.00	< 1.00	< 1.00
DDT	< .100	< .100	< .100
Delta BHC	< .500	< .500	< .500
Dieldrin	< 1.00	< 1.00	< 1.00
Endrin	< .100	< .100	< .100
Endrin aldehyde	< .500	< .500	< .500
Endrin sulfate	< .100	< .100	< .100
Heptachlor	< .500	< .500	< .500

Table A3: (Page 4 of 4)

Sampling Depth (in feet)	5.0	25.0	14.5
Heptachlor epoxide	< .500	< .500	< .500
Lindane	< .500	< .500	< .500
Methoxychlor	< .500	< .500	< .500
PCB 1016	< 5.00	< 5.00	< 5.00
PCB 1221	< 5.00	< 5.00	< 5.00
PCB 1232	< 5.00	< 5.00	< 5.00
PCB 1242	< 5.00	< 5.00	< 5.00
PCB 1254	< 10.0	< 10.0	< 10.0
PCB 1260	< 1.00	< 1.00	< 1.00
Toxaphene	< 1.00	< 1.00	< 1.00
Metals			
Arsenic	230	245	288
Cadmium	.840	.601	1.88
Chromium	7.45	7.77	10.7
Copper	< 1.70	< 1.70	< 1.70
Iron	974	700	1080
Lead	< 5.00	< 5.00	< 5.00
Mercury	< .200	< .200	< .200
Selenium	< 2.50	< 2.50	< 2.50
Silver	< .200	< .200	< .200
Zinc	42.3	24.6	55.4

[1] concentrations in micrograms per liter (µg/l)

BHC = hexachlorocyclohexane
DDD = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethane
DDE = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethene
DDT = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1,1-trichloroethane
N/A = no analysis available
NDMA = n-nitrosodimethylamine
PCB = polychlorinated biphenyl
< = compound not detected at or above method detection limit or method reporting limit

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BENCH/PILOT-SCALE TESTING PROGRAM

Table A4: Bench/Pilot-Scale Testing Program Analytical Results
(Page 1 of 3)

Peroxidation Systems, Inc.									
Sample Date:	5/6/89	5/4/89	5/4/89	5/4/89	5/17/89	5/17/89	5/17/89	5/24/89	5/24/89
Sample Type:	Untreated Wastewater	Treated Wastewater Run 1	Treated Wastewater Run 2	Treated Wastewater Run 3	Treated Wastewater Run 4	Treated Wastewater Run 5	Treated Wastewater Run 6	Treated Wastewater Run 7	Treated Wastewater Run 8
Analytes	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Hydrazine Fuel Compounds									
Hydrazine	1,100,000	150,000	15	12	50 U	50 U	50 U	20 U	20 U
MMH	62,000	4,300	1,100	290	240,000	990 U	200,000	990 U	990 U
UDMH	960,000	43,000	21	13	56	18	50 U	20 U	20 U
NDMA	120	5,300	5.0	3.2	0.12	1.2	0.11	0.31	0.02
Purgeable Halocarbons								NA	
Chloroethane	10 U	49	10 U	10 U	0.5 U	5 U	0.5 U		0.5 U
Chloroform	60	25	10	5 U	0.5 U	5 U	0.5 U		32
Chloromethane	10 U	500	500	33	0.5 U	5 U	0.5 U		5.0 U
Methylene chloride	31	25	12	5 U	0.8	14	0.8		8.8
Tetrachloroethane	5 U	5 U	5 U	5 U	0.6	5 U	0.6		
Metals	NA	NA	NA	NA	NA	NA	NA	NA	
Total arsenic									11
Total chromium									300
Total copper									75
Total mercury									0.5
Total molybdenum									200
Total nickel									220
Total thallium									100
Total zinc									60
Total iron									2,900

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Solarchem Environmental Systems, Inc.

Analytes	Sample Date: 5/12/89 Sample Type: Treated Wastewater Run 1 (µg/l)	5/19/89 Untreated Wastewater (µg/l)	5/29/89 Treated Wastewater Run 2 (µg/l)	5/29/89 Treated Wastewater Run 3 (µg/l)	5/30/89 Treated Wastewater Run 4 (µg/l)	Final Treated Wastewater Run 5 (µg/l)	Offgas Run 5 (µg/l)
Hydrazine Fuel Compounds							
Hydrazine	20 U	1,500,000	2,100,000	2,000,000	490	10 U	0.002 U
MMH	8,100	580,000	330,000	260,000	24,000	250 U	0.05 U
UDMH	20 U	1,800,000	2,000,000	1,800,000	230	5 U	0.002 U
NDMA	1.2	72	370	120	11,000	0.07	0.007
Purgeable Halocarbons	NA						NA
Chloroform		44	65	70	5 U	0.5 U	
Methylene chloride		18	140	250	5 U	1.2	
Metals	NA		NA	NA	NA		NA
Total arsenic		18				19	
Total barium		100 U				200	
Total chromium		10 U				260	
Total copper		25 U				70	
Total lead		3 U				10	
Total mercury		0.2				1.9	
Total nickel		40 U				170	
Total zinc		20 U				280	
Total iron		5,600				14,000	

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ULTROX International

Sample Date:	5/15/89	5/15/89	5/16/89	5/19/89	5/19/89	5/22/89	5/22/89	5/25/89	5/25/89
Sample Type:	Untreated Wastewater	Treated Wastewater Run 1	Treated Wastewater Run 2	Treated Wastewater Run 3	Treated Wastewater Run 4	Treated Wastewater Run 5	Offgas Run 5	Treated Wastewater Run 6	Offgas Run 6
Analytes	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)
Hydrazine Fuel Compounds									
Hydrazine	610,000	5.0 U	30	50 U	50 U	50 U	0.015 U	43	0.005 U
MMH	99,000	250 U	330	1,000	990 U	1,000 U	0.3 U	1,000 U	0.2 U
UDMH	540,000	20	89	6.8	7.4	7.3	0.0015 U	56	0.005 U
NDMA	37	0.20	0.23	0.03	0.90	0.96	0.16	0.20	0.04
Purgeable Halocarbons		NA	NA		NA	NA	NA		NA
Chloroform	160			5 U				5 U	
Methylene chloride	200			11				12	
Metals	NA	NA	NA	NA	NA	NA	NA		NA
Total arsenic								16	
Total chromium								50	
Total lead								22	
Total mercury								0.6	
Total nickel								260	
Total thallium								200	
Total zinc								90	
Total iron								220	

µg/l = micrograms per liter
MMH = monomethyl hydrazine
UDMH = unsymmetrical dimethyl hydrazine
NDMA = n-nitrosodimethylamine
NA = not applicable; sample not received or analysis not required
U = not detected at or below specified reporting limit

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FULL-SCALE STARTUP TESTING PROGRAM

Table A5: Batch 1 Investigative Sample Results - Full-Scale Startup Testing Program[1]
(Page 1 of 4)

Site Identification Sampling Date Treatment time (in hours)	IRAH-01-I 01/11/90 0.0	IRAH-02-E 01/12/90 12.2	IRAH-04-E[2] 01/26/90 19.3	IRAH-07-E[3] 02/13/90 32.6
Hydrazine Fuel Compounds/NDMA				
Hydrazine	1000000	< 2.50	< 2.50	N/A
Monomethyl hydrazine	320000	2.90	< 2.50	N/A
Unsymmetrical dimethyl hydrazine	810000	< 2.50	< 2.50	N/A
n-Nitrosodimethylamine	120	N/A	.230	.690
Volatile Organics				
Acetone	32.0	32.5	N/A	N/A
Acrolein	< 10.0	< 10.0	N/A	N/A
Acrylonitrile	< 10.0	< 10.0	N/A	N/A
Benzene	< 5.00	< 5.00	N/A	N/A
Bromodichloromethane	< 5.00	< 5.00	N/A	N/A
Bromoform	< 5.00	< 5.00	N/A	N/A
Bromomethane	< 10.0	< 10.0	N/A	N/A
Carbon disulfide	< 5.00	< 5.00	N/A	N/A
Carbon tetrachloride	< 5.00	< 5.00	N/A	N/A
Chlorobenzene	< 5.00	< 5.00	N/A	N/A
Chloroethane	< 10.0	< 10.0	N/A	N/A
Chloroform	106	< 5.00	N/A	N/A
Chloromethane	< 10.0	37.5	N/A	N/A
Dibromochloromethane	< 5.00	< 5.00	N/A	N/A
Dibromochloropropane	< .130	< .130	N/A	N/A
1,1-Dichloroethane	< 5.00	< 5.00	N/A	N/A
1,2-Dichloroethane	< 5.00	< 5.00	N/A	N/A
1,1-Dichloroethene	< 5.00	< 5.00	N/A	N/A
1,2-Dichloropropane	< 5.00	< 5.00	N/A	N/A
Dicyclopentadiene	< 9.31	< 9.31	N/A	N/A
Dimethyl disulfide	53.0	< 1.16	N/A	N/A
Ethylbenzene	< 5.00	< 5.00	N/A	N/A
2-Hexanone	< 10.0	< 10.0	N/A	N/A
Methylethyl ketone	< 10.0	< 10.0	N/A	N/A
Methylene chloride	110	23.2	N/A	N/A
Methylisobutyl ketone	< 10.0	< 10.0	N/A	N/A
o,p-Xylene	< 5.00	< 5.00	N/A	N/A
Styrene	< 5.00	< 5.00	N/A	N/A
1,1,2,2-Tetrachloroethane	< 5.00	< 5.00	N/A	N/A
Tetrachloroethene	< 5.00	< 5.00	N/A	N/A
Toluene	< 5.00	< 5.00	N/A	N/A
1,1,1-Trichloroethane	< 5.00	< 5.00	N/A	N/A
1,1,2-Trichloroethane	< 5.00	< 5.00	N/A	N/A
Trichloroethene	< 5.00	< 5.00	N/A	N/A
Vinyl acetate	< 10.0	< 10.0	N/A	N/A
Vinyl chloride	< 10.0	< 10.0	N/A	N/A
cis-1,3-Dichloropropylene	< 5.00	< 5.00	N/A	N/A
trans-1,2-Dichloroethylene	< 5.00	< 5.00	N/A	N/A
trans-1,3-Dichloropropene	< 5.00	< 5.00	N/A	N/A

Table A5: (Page 2 of 4)

Site Identification Sampling Date Treatment time (in hours)	IRAH-01-I 01/11/90 0.0	IRAH-02-E 01/12/90 12.2	IRAH-04-E[2] 01/26/90 19.3	IRAH-07-E[3] 02/13/90 32.6
Semivolatiles				
Acenaphthene	< .385	< .385	N/A	N/A
Acenaphthylene	< .343	< .343	N/A	N/A
Anthracene	< .634	< .634	N/A	N/A
Atrazine	4.85	N/A	N/A	N/A
Benzo [A] anthracene	< .302	< .302	N/A	N/A
Benzo [A] pyrene	< .291	< .291	N/A	N/A
Benzo [B] fluoranthene	< .842	< .842	N/A	N/A
Benzo [G,H,I] perylene	< 1.25	< 1.25	N/A	N/A
Benzo [K] fluoranthene	< 1.73	< 1.73	N/A	N/A
Benzoic acid	< 3.32	< 3.32	N/A	N/A
Benzothiazole	14.9	< 1.14	N/A	N/A
Benzyl alcohol	< .728	< .728	N/A	N/A
4-Bromophenylphenyl ether	< .603	< .603	N/A	N/A
Butylbenzyl phthalate	< 2.20	< 2.20	N/A	N/A
4-Chloroaniline	< .707	< .707	N/A	N/A
2-Chloronaphthalene	< .478	< .478	N/A	N/A
2-Chlorophenol	< .281	< .281	N/A	N/A
4-Chlorophenylmethyl sulfide	< 1.08	< 1.08	N/A	N/A
4-Chlorophenylmethyl sulfone	< 2.24	< 2.24	N/A	N/A
4-Chlorophenylmethyl sulfoxide	< 1.98	< 1.98	N/A	N/A
4-Chlorophenylphenyl ether	< .832	< .832	N/A	N/A
Chrysene	< 3.21	< 3.21	N/A	N/A
di-n-Butyl phthalate	< 1.80	< 1.80	N/A	N/A
di-n-Octyl phthalate	< 5.13	< 5.13	N/A	N/A
Dibenz [A,H] anthracene	< 1.70	< 1.70	N/A	N/A
Dibenzofuran	< .354	< .354	N/A	N/A
1,3-Dichlorobenzene	< .104	< .104	N/A	N/A
1,4-Dichlorobenzene	< .239	< .239	N/A	N/A
1,2-Dichlorobenzene	< .416	< .416	N/A	N/A
3,3'-Dichlorobenzidine	< 4.04	< 4.04	N/A	N/A
2,4-Dichlorophenol	< .364	< .364	N/A	N/A
Diethyl phthalate	< 1.76	< 1.76	N/A	N/A
Diisopropyl methylphosphonate	< 10.1	< 10.1	N/A	N/A
Dimethyl phthalate	< .874	< .874	N/A	N/A
Dimethylmethyl phosphonate	< 16.3	< 16.3	N/A	N/A
2,4-Dimethylphenol	< .281	< .281	N/A	N/A
4,6-Dinitro-2-cresol	< 3.15	< 3.15	N/A	N/A
2,4-Dinitrophenol	< 3.55	< 3.55	N/A	N/A
2,6-Dinitrotoluene	< 1.93	< 1.93	N/A	N/A
2,4-Dinitrotoluene	< 2.55	< 2.55	N/A	N/A
Dithiane	< 3.34	< 3.34	N/A	N/A
Fluoranthene	< 1.44	< 1.44	N/A	N/A
Fluorene	< .905	< .905	N/A	N/A
Hexachlorobenzene	< .707	< .707	N/A	N/A
Hexachlorobutadiene	< .551	< .551	N/A	N/A
Hexachlorocyclopentadiene	< .083	< .083	N/A	N/A
Hexachloroethane	< .291	< .291	N/A	N/A
Indeno [1,2,3-C,D] pyrene	< 1.67	< 1.67	N/A	N/A

Table A5: (Page 3 of 4)

Site Identification Sampling Date Treatment time (in hours)	IRAH-01-I 01/11/90 0.0	IRAH-02-E 01/12/90 12.2	IRAH-04-E[2] 01/26/90 19.3	IRAH-07-E[3] 02/13/90 32.6
Isodrin	< .056	< .056	N/A	N/A
Isophorone	< .374	< .374	N/A	N/A
Malathion	< .373	N/A	N/A	N/A
3-Methyl-4-chlorophenol	< .988	< .988	N/A	N/A
2-Methylnaphthalene	< .894	< .894	N/A	N/A
4-Methylphenol	< .832	< .832	N/A	N/A
2-Methylphenol	< .884	< .884	N/A	N/A
n-Nitrosodiphenylamine	< .551	< .551	N/A	N/A
Naphthalene	< 270	< .270	N/A	N/A
2-Nitroaniline	< 2.38	< 2.38	N/A	N/A
3-Nitroaniline	< 3.17	< 3.17	N/A	N/A
4-Nitroaniline	< 3.99	< 3.99	N/A	N/A
Nitrobensene	< 1.14	< 1.14	N/A	N/A
2-Nitrophenol	< 1.86	< 1.86	N/A	N/A
4-Nitrophenol	< 3.90	< 3.90	N/A	N/A
Nitroso di-n-propylamine	< 1.42	< 1.42	N/A	N/A
1,4-Oxathiane	< 1.35	< 1.35	N/A	N/A
Parathion	< .647	N/A	N/A	N/A
Pentachlorophenol	< 1.89	< 1.89	N/A	N/A
Phenanthrene	< .478	< .478	N/A	N/A
Phenol	< 1.06	< 1.06	N/A	N/A
Pyrene	< 1.73	< 1.73	N/A	N/A
Supona	< .787	N/A	N/A	N/A
1,2,4-Trichlorobensene	< .541	< .541	N/A	N/A
2,4,6-Trichlorophenol	< .354	< .354	N/A	N/A
2,4,5-Trichlorophenol	< .957	< .957	N/A	N/A
Vapona	< .384	N/A	N/A	N/A
bis(2-Chloroethoxy) methane	< .499	< .499	N/A	N/A
bis(2-Chloroethyl) ether	< .291	< .291	N/A	N/A
bis(2-Chloroisopropyl) ether	< 1.09	< 1.09	N/A	N/A
bis(2-Ethylhexyl) phthalate	< 3.26	< 3.26	N/A	N/A
Pesticides				
Aldrin	< .155	< .031	N/A	N/A
Alpha BHC	< .155	< .031	N/A	N/A
Beta BHC	< .155	< .031	N/A	N/A
Beta endosulfan	< .315	< .062	N/A	N/A
Chlordane	< 1.55	< .313	N/A	N/A
DDD	< .315	< .062	N/A	N/A
DDE	< .315	< .062	N/A	N/A
DDT	< .315	< .062	N/A	N/A
Delta BHC	< .155	< .031	N/A	N/A
Dieldrin	< .315	< .062	N/A	N/A
Endrin	< .315	< .062	N/A	N/A
Endrin aldehyde	< 1.55	< .313	N/A	N/A
Endrin sulfate	< .315	< .062	N/A	N/A
Heptachlor epoxide	< .155	< .031	N/A	N/A
Methoxychlor	< 1.55	< .313	N/A	N/A
PCB 1016	< 1.55	< .313	N/A	N/A

Table A5: (Page 4 of 4)

Site Identification Sampling Date Treatment time (in hours)	IRAH-01-I 01/11/90 0.0	IRAH-02-E 01/12/90 12.2	IRAH-04-E[2] 01/26/90 19.3	IRAH-07-E[3] 02/13/90 32.6
PCB 1221	< 1.55	< .313	N/A	N/A
PCB 1232	< 1.55	< .313	N/A	N/A
PCB 1242	< 1.55	< .313	N/A	N/A
PCB 1254	< 3.15	< .625	N/A	N/A
PCB 1260	< 3.15	< .625	N/A	N/A
Toxaphene	< 3.15	< .625	N/A	N/A
Metals				
Arsenic	16.1	6.32	N/A	N/A
Cadmium	< .200	3.00	N/A	N/A
Chromium	< 22.4	645	N/A	N/A
Copper	< 10.0	16.6	N/A	N/A
Lead	< 2.00	< 2.00	N/A	N/A
Mercury	.658	.962	N/A	N/A
Selenium	< 2.00	< 4.00	N/A	N/A
Silver	.224	.968	N/A	N/A
Zinc	< 20.0	118	N/A	N/A

[1] concentrations in micrograms per liter (μg/l)

[2] first retreatment of batch 1

[3] second retreatment of batch 1

< = not detected at or above method detection limit or method reporting limit
BHC = hexachlorocyclohexane
DDD = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethane
DDE = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1-dichloroethene
DDT = 2-(ortho-chlorophenyl)-2-(para-chlorophenyl)-1,1,1-trichloroethane
N/A = no analysis available
NDMA = n-nitrosodimethylamine
PCB = polychlorinated biphenyl

20003,620.10 - TR
1220010791

Table A6: Batch 2 Investigative Sample Results - Full-Scale Startup Testing Program[1]

Site Identification	IRAH-05-E	IRAH-06-E[2]
Sampling Date	01/31/90	02/12/90
Treatment time (in hours)	18.2	59.5
Hydrazine Fuel Compounds/NDMA		
Hydrazine	< 2.50	N/A
Monomethyl hydrazine	< 2.50	N/A
Unsymmetrical dimethyl hydrazine	< 2.50	N/A
n-Nitrosodimethylamine	.530	2.50

[1] concentrations in micrograms per liter ($\mu g/l$)

[2] first retreatment of batch 2

< = not detected at or above method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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1220010791

Table A7: Batch 3 Investigative Sample Results - Full-Scale Startup Testing Program[1]
(Page 1 of 6)

Site Identification	IRAH-08-I	IRAH-01-KB	IRAH-02-KB	IRAH-03-KB	IRAH-04-KB
Sampling Date	02/25/90	02/25/90	02/25/90	02/25/90	02/25/90
Treatment time (in hours)	0.0	2.0	4.0	6.0	8.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	1200000	33000	750	11.0	< 2.50
Monomethyl hydrazine	89000	4400	730	5.40	4.30
Unsymmetrical dimethyl hydrazine	5300000	26000	750	< 2.50	< 2.50
n-Nitrosodimethylamine	285	8280	5300	880	625
Volatile Organics					
Benzene	3.90	N/A	N/A	N/A	N/A
Bromodichloromethane	< .200	N/A	N/A	N/A	N/A
Bromoform	< .200	N/A	N/A	N/A	N/A
Bromomethane	< .200	N/A	N/A	N/A	N/A
Carbon tetrachloride	< .200	N/A	N/A	N/A	N/A
Chlorobenzene	< .200	N/A	N/A	N/A	N/A
Chloroethane	1.80	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	< .200	N/A	N/A	N/A	N/A
Chloroform	< 86.0	N/A	N/A	N/A	N/A
Chloromethane	31.0	N/A	N/A	N/A	N/A
Dibromochloromethane	< .200	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	< .200	N/A	N/A	N/A	N/A
1,1-Dichloroethane	1.40	N/A	N/A	N/A	N/A
1,2-Dichloroethane	2.80	N/A	N/A	N/A	N/A
1,1-Dichloroethene	.360	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	< .200	N/A	N/A	N/A	N/A
1,2-Dichloropropane	< .200	N/A	N/A	N/A	N/A
1,3-Dichloropropene	< .200	N/A	N/A	N/A	N/A
Ethylbenzene	< .500	N/A	N/A	N/A	N/A
Methylene chloride	69.0	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	< .200	N/A	N/A	N/A	N/A
Tetrachloroethene	< .200	N/A	N/A	N/A	N/A
Toluene	< .500	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	.470	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	< .200	N/A	N/A	N/A	N/A
Trichloroethene	.520	N/A	N/A	N/A	N/A
Trichlorofluoromethane	< .200	N/A	N/A	N/A	N/A
Vinyl chloride	< .200	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	< .200	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	< .200	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	< .200	N/A	N/A	N/A	N/A

Table A7: (Page 2 of 6)

Site Identification Sampling Date Treatment time (in hours)	IRAH-05-KB 02/25/90 10.0	IRAH-07-KB 02/25/90 12.0	IRAH-08-KB 02/25/90 14.0	IRAH-09-KB 02/25/90 16.0	IRAH-10-KB 02/25/90 18.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
Monomethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
Unsymmetrical dimethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
n-Nitrosodimethylamine	190	87.9	52.6	30.0	27.4
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A7: (Page 3 of 6)

Site Identification Sampling Date Treatment time (in hours)	IRAH-11-KB 02/26/90 20.0	IRAH-13-KB 02/26/90 22.0	IRAH-14-KB 02/25/90 24.0	IRAH-15-KB 02/26/90 26.0	IRAH-16-KB 02/26/90 28.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
Monomethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
Unsymmetrical dimethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
n-Nitrosodimethylamine	30.0	41.9	50.0	43.3	29.4
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A7: (Page 4 of 6)

Site Identification	IRAH-17-KB	IRAH-19-KB	IRAH-01-KA	IRAH-02-KA	IRAH-04-KA
Sampling Date	02/26/90	02/26/90	02/26/90	02/26/90	02/28/90
Treatment time (in hours)	30.0	30.0	30.5	32.0	34.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	< 2.50	N/A	N/A	< 2.50	< 2.50
Monomethyl hydrazine	< 2.50	N/A	N/A	< 2.50	< 2.50
Unsymmetrical dimethyl hydrazine	< 2.50	N/A	N/A	< 2.50	< 2.50
n-Nitrosodimethylamine	31.5	N/A	N/A	.114	.255
Volatile Organics					
Benzene	N/A	< .500	< .500	N/A	N/A
Bromodichloromethane	N/A	< .200	< .200	N/A	N/A
Bromoform	N/A	< .200	< .200	N/A	N/A
Bromomethane	N/A	< .200	< .200	N/A	N/A
Carbon tetrachloride	N/A	< .200	< .200	N/A	N/A
Chlorobenzene	N/A	< .200	< .200	N/A	N/A
Chloroethane	N/A	< .200	< .200	N/A	N/A
2-Chloroethylvinyl ether	N/A	< .200	< .200	N/A	N/A
Chloroform	N/A	< .200	< .200	N/A	N/A
Chloromethane	N/A	14.0	< .200	N/A	N/A
Dibromochloromethane	N/A	< .200	< .200	N/A	N/A
Dichlorodifluoromethane	N/A	< .200	< .200	N/A	N/A
1,1-Dichloroethane	N/A	< .200	< .200	N/A	N/A
1,2-Dichloroethane	N/A	< .200	< .200	N/A	N/A
1,1-Dichloroethene	N/A	< .200	< .200	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	< .200	< .200	N/A	N/A
1,2-Dichloropropane	N/A	< .200	< .200	N/A	N/A
1,3-Dichloropropene	N/A	< .200	< .200	N/A	N/A
Ethylbenzene	N/A	< .500	< .500	N/A	N/A
Methylene chloride	N/A	.830	< 21.0	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	< .200	< .200	N/A	N/A
Tetrachloroethene	N/A	< .200	< .200	N/A	N/A
Toluene	N/A	2.50	2.30	N/A	N/A
1,1,1-Trichloroethane	N/A	< .200	< .200	N/A	N/A
1,1,2-Trichloroethane	N/A	< .200	< .200	N/A	N/A
Trichloroethene	N/A	< .200	< .200	N/A	N/A
Trichlorofluoromethane	N/A	< .200	< .200	N/A	N/A
Vinyl chloride	N/A	< .200	< .200	N/A	N/A
1,2-Dichlorobenzene	N/A	< .200	< .200	N/A	N/A
1,3-Dichlorobenzene	N/A	< .200	< .200	N/A	N/A
1,4-Dichlorobenzene	N/A	< .200	< .200	N/A	N/A

Table A7: (Page 5 of 6)

Site Identification Sampling Date Treatment time (in hours)	IRAH-05-KA 02/28/90 36.0	IRAH-06-KA 02/28/90 38.0	IRAH-07-KA 02/28/90 40.0	IRAH-09-KA 02/28/90 42.0	IRAH-10-KA 02/28/90 44.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	< 2.50	< 2.50	< 2 50	< 2.50	< 2.50
Monomethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
Unsymmetrical dimethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50	< 2.50
n-Nitrosodimethylamine	.062	.234	.148	.132	.203
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A7: (Page 6 of 6)

Site Identification Sampling Date Treatment time (in hours)	IRAH-11-KA 02/28/90 46.0	IRAH-12-KA 02/28/90 48.0	IRAH-13-KA 02/28/90 32.0	IRAH-09-E 03/01/90 50.0
Hydrazine Fuel Compounds/NDMA				
Hydrazine	< 2.50	< 2.50	< 2.50	< 2.50
Monomethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50
Unsymmetrical dimethyl hydrazine	< 2.50	< 2.50	< 2.50	< 2.50
n-Nitrosodimethylamine	.163	.100	.127	5.81
Volatile Organics				
Benzene	N/A	N/A	< .500	< .500
Bromodichloromethane	N/A	N/A	< .200	< .200
Bromoform	N/A	N/A	< .200	< .200
Bromomethane	N/A	N/A	< .200	< .200
Carbon tetrachloride	N/A	N/A	< .200	< .200
Chlorobenzene	N/A	N/A	< .200	< .200
Chloroethane	N/A	N/A	< .200	< .200
2-Chloroethylvinyl ether	N/A	N/A	< .200	< .200
Chloroform	N/A	N/A	1.00	< .200
Chloromethane	N/A	N/A	< .200	N/A
Dibromochloromethane	N/A	N/A	< .200	< .200
Dichlorodifluoromethane	N/A	N/A	< .200	< .200
1,1-Dichloroethane	N/A	N/A	< .200	< .200
1,2-Dichloroethane	N/A	N/A	< .200	< .200
1,1-Dichloroethene	N/A	N/A	< .200	.620
1,2-Dichloroethenes (cis & trans)	N/A	N/A	< .200	< .200
1,2-Dichloropropane	N/A	N/A	< .200	< .200
1,3-Dichloropropene	N/A	N/A	< .200	< .200
Ethylbenzene	N/A	N/A	< .500	< .500
Methylene chloride	N/A	N/A	22.0	1.70
1,1,2,2-Tetrachloroethane	N/A	N/A	< .200	< .200
Tetrachloroethene	N/A	N/A	< .200	< .200
Toluene	N/A	N/A	2.90	< .500
1,1,1-Trichloroethane	N/A	N/A	.350	8.00
1,1,2-Trichloroethane	N/A	N/A	< .200	< .200
Trichloroethene	N/A	N/A	< .200	.620
Trichlorofluoromethane	N/A	N/A	< .200	< .200
Vinyl chloride	N/A	N/A	< .200	< .200
1,2-Dichlorobenzene	N/A	N/A	< .200	< .200
1,3-Dichlorobenzene	N/A	N/A	< .200	< .200
1,4-Dichlorobenzene	N/A	N/A	< .200	< .200

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A8: Batch 4 Investigative Sample Results - Full-Scale Startup Testing Program[1]
(Page 1 of 3)

Site Identification	IRAH-11-I	IRAH-21-KB	IRAH-23-KB	IRAH-25-KB	IRAH-15-KA
Sampling Date	03/15/90	03/15/90	03/15/90	03/15/90	03/16/90
Treatment time (in hours)	0.0	4.0	8.0	12.0	16.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	250000	210	14.0	2.50	4.00
Monomethyl hydrazine	120000	350	34.0	9.90	8.20
Unsymmetrical dimethyl hydrazine	380000	13000	16.0	570	5.30
n-Nitrosodimethylamine	23400	13000	9190	5910	173
Volatile Organics					
Benzene	< .500	N/A	N/A	N/A	< .500
Bromodichloromethane	< .200	N/A	N/A	N/A	< .200
Bromoform	< .200	N/A	N/A	N/A	< .200
Bromomethane	< .200	N/A	N/A	N/A	< .200
Carbon tetrachloride	< .200	N/A	N/A	N/A	< .200
Chlorobenzene	< .200	N/A	N/A	N/A	< .200
Chloroethane	5.50	N/A	N/A	N/A	2.60
2-Chloroethylvinyl ether	< .200	N/A	N/A	N/A	< .200
Chloroform	51.0	N/A	N/A	N/A	5.50
Chloromethane	330	N/A	N/A	N/A	320
Dibromochloromethane	< .200	N/A	N/A	N/A	< .200
Dichlorodifluoromethane	< .200	N/A	N/A	N/A	< .200
1,2-Dichloroethane	.440	N/A	N/A	N/A	< .200
1,1-Dichloroethane	.490	N/A	N/A	N/A	< .200
1,1-Dichloroethene	< .200	N/A	N/A	N/A	< .200
1,2-Dichloroethenes (cis & trans)	< .200	N/A	N/A	N/A	< .200
1,2-Dichloropropane	< .200	N/A	N/A	N/A	< .200
1,3-Dichloropropene	< .200	N/A	N/A	N/A	< .200
Ethylbenzene	< .500	N/A	N/A	N/A	< .500
Methylene chloride	42.0	N/A	N/A	N/A	9.80
1,1,2,2-Tetrachloroethane	< .200	N/A	N/A	N/A	< .200
Tetrachloroethene	< .200	N/A	N/A	N/A	< .200
Toluene	6.80	N/A	N/A	N/A	< .500
1,1,1-Trichloroethane	< .200	N/A	N/A	N/A	.880
1,1,2-Trichloroethane	< .200	N/A	N/A	N/A	< .200
Trichloroethene	< .200	N/A	N/A	N/A	2.80
Trichlorofluoromethane	< .200	N/A	N/A	N/A	< .200
Vinyl chloride	< .200	N/A	N/A	N/A	.340
1,2-Dichlorobenzene	< .200	N/A	N/A	N/A	< .200
1,3-Dichlorobenzene	< .200	N/A	N/A	N/A	< .200
1,4-Dichlorobenzene	< .200	N/A	N/A	N/A	< .200

Table A8: (Page 2 of 3)

Site Identification Sampling Date Treatment time (in hours)	IRAH-19-KA 03/16/90 18.0	IRAH-20-KA 03/16/90 20.0	IRAH-21-KA 03/16/90 22.0	IRAH-22-KA 03/16/90 24.0	IRAH-23-KA 03/16/90 26.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	.670	.470	< .250	< .250	< .250
Monomethyl hydrazine	< .250	4.60	1.70	.310	.870
Unsymmetrical dimethyl hydrazine	< .250	.470	.320	< .250	< .250
n-Nitrosodimethylamine	47.7	8.79	N/A	4.32	1.73
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	< 50.0
Bromodichloromethane	N/A	N/A	N/A	N/A	< 20.0
Bromoform	N/A	N/A	N/A	N/A	< 20.0
Bromomethane	N/A	N/A	N/A	N/A	< 20.0
Carbon tetrachloride	N/A	N/A	N/A	N/A	< 20.0
Chlorobenzene	N/A	N/A	N/A	N/A	< 20.0
Chloroethane	N/A	N/A	N/A	N/A	390
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	< 20.0
Chloroform	N/A	N/A	N/A	N/A	< 20.0
Chloromethane	N/A	N/A	N/A	N/A	330
Dibromochloromethane	N/A	N/A	N/A	N/A	< 20.0
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	< .200
1,1-Dichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,1-Dichloroethene	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloropropane	N/A	N/A	N/A	N/A	< 20.0
1,3-Dichloropropene	N/A	N/A	N/A	N/A	< 20.0
Ethylbenzene	N/A	N/A	N/A	N/A	< 50.0
Methylene chloride	N/A	N/A	N/A	N/A	< 20.0
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	< 20.0
Tetrachloroethene	N/A	N/A	N/A	N/A	< 20.0
Toluene	N/A	N/A	N/A	N/A	< 50.0
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	< 20.0
Trichloroethene	N/A	N/A	N/A	N/A	< 20.0
Trichlorofluoromethane	N/A	N/A	N/A	N/A	< 20.0
Vinyl chloride	N/A	N/A	N/A	N/A	49.0
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	< 100
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	< 100
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	< 100

Table A8: (Page 3 of 3)

Site Identification	IRAH-29-KA	IRAH-31-KA	IRAH-15-E
Sampling Date	03/16/90	03/16/90	03/16/90
Treatment time (in hours)	30.0	34.0	46.0
Hydrazine Fuel Compounds/NDMA			
Hydrazine	< .250	< .250	.940
Monomethyl hydrazine	.760	.290	.850
Unsymmetrical dimethyl hydrazine	< .250	< 250	.450
n-Nitrosodimethylamine	1.20	.738	.562
Volatile Organics			
Benzene	N/A	N/A	< 50.0
Bromodichloromethane	N/A	N/A	< 20.0
Bromoform	N/A	N/A	< 20.0
Bromomethane	N/A	N/A	< 20.0
Carbon tetrachloride	N/A	N/A	< 20.0
Chlorobenzene	N/A	N/A	< 50.0
Chloroethane	N/A	N/A	< 20.0
2-Chloroethylvinyl ether	N/A	N/A	< 20.0
Chloroform	N/A	N/A	< 20.0
Chloromethane	N/A	N/A	< 20.0
Dibromochloromethane	N/A	N/A	< 20.0
Dichlorodifluoromethane	N/A	N/A	< 20.0
1,1-Dichloroethane	N/A	N/A	< 20.0
1,2-Dichloroethane	N/A	N/A	< 20.0
1,1-Dichloroethene	N/A	N/A	< 20.0
1,2-Dichloroethenes (cis & trans)	N/A	N/A	< 20.0
1,2-Dichloropropane	N/A	N/A	< 20.0
1,3-Dichloropropene	N/A	N/A	< 20.0
Ethylbenzene	N/A	N/A	< 50.0
Methylene chloride	N/A	N/A	340
1,1,2,2-Tetrachloroethane	N/A	N/A	< 20.0
Tetrachloroethene	N/A	N/A	< 20.0
Toluene	N/A	N/A	64.0
1,1,1-Trichloroethane	N/A	N/A	< 20.0
1,1,2-Trichloroethane	N/A	N/A	< 20.0
Trichloroethene	N/A	N/A	< 20.0
Trichlorofluoromethane	N/A	N/A	< 20.0
Vinyl chloride	N/A	N/A	35.0
1,2-Dichlorobenzene	N/A	N/A	< 100
1,3-Dichlorobenzene	N/A	N/A	< 100
1,4-Dichlorobenzene	N/A	N/A	< 100

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A9: Batch 5 Investigative Sample Results - Full-Scale Startup Testing Program[1]
(Page 1 of 3)

Site Identification	IRAH-13-I	IRAH-33-KA	IRAH-34-KA	IRAH-35-KA	IRAH-36-KA
Sampling Date	03/22/90	03/22/90	03/22/90	03/22/90	03/22/90
Treatment time (in hours)	0.0	2.0	4.0	6.0	8.0
Hydrazine Fuel Compounds/ NDMA					
Hydrazine	96000	N/A	28000	N/A	6400
Monomethyl hydrazine	20000	N/A	5300	N/A	2200
Unsymmetrical dimethyl hydrazine	250000	N/A	180000	N/A	3000
n-Nitrosodimethylamine	59200	41500	5200	4000	1480
Volatile Organics					
Benzene	< 250	N/A	N/A	N/A	N/A
Bromodichloromethane	< 100	N/A	N/A	N/A	N/A
Bromoform	< 100	N/A	N/A	N/A	N/A
Bromomethane	< 100	N/A	N/A	N/A	N/A
Carbon tetrachloride	< 100	N/A	N/A	N/A	N/A
Chlorobenzene	< 100	N/A	N/A	N/A	N/A
Chloroethane	< 100	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	< 100	N/A	N/A	N/A	N/A
Chloroform	53.0	N/A	N/A	N/A	N/A
Chloromethane	3600	N/A	N/A	N/A	N/A
Dibromochloromethane	< 100	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	< 100	N/A	N/A	N/A	N/A
1,1-Dichloroethane	< 100	N/A	N/A	N/A	N/A
1,2-Dichloroethane	< 100	N/A	N/A	N/A	N/A
1,1-Dichloroethene	< 100	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	< 100	N/A	N/A	N/A	N/A
1,2-Dichloropropane	< 100	N/A	N/A	N/A	N/A
1,3-Dichloropropene	< 100	N/A	N/A	N/A	N/A
Ethylbenzene	< 250	N/A	N/A	N/A	N/A
Methylene chloride	280	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	< 100	N/A	N/A	N/A	N/A
Tetrachloroethene	< 100	N/A	N/A	N/A	N/A
Toluene	< 250	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	< 100	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	< 100	N/A	N/A	N/A	N/A
Trichloroethene	< 100	N/A	N/A	N/A	N/A
Trichlorofluoromethane	< 100	N/A	N/A	N/A	N/A
Vinyl chloride	< 100	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	< 100	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	< 100	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	< 100	N/A	N/A	N/A	N/A

Table A9: (Page 2 of 3)

Site Identification Sampling Date Treatment time (in hours)	IRAH-37-KA 03/22/90 10.0	IRAH-38-KA 03/22/90 12.0	IRAH-39-KA 03/22/90 24.0	IRAH-40-KA 03/22/90 26.0	IRAH-42-KA 03/22/90 30.0
Hydrazine Fuel Compounds / NDMA					
Hydrazine	N/A	440	.250	.880	.270
Monomethyl hydrazine	N/A	6.30	1.30	1.10	.920
Unsymmetrical dimethyl hydrazine	N/A	.840	.840	< .250	< .250
n-Nitrosodimethylamine	514	63.1	.679	51.9	33.6
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A9: (Page 3 of 3)

Site Identification	IRAH-44-KA
Sampling Date	03/23/90
Treatment time (in hours)	34.0
Hydrazine Fuel Compounds / NDMA	
Hydrazine	< .250
Monomethyl hydrazine	.750
Unsymmetrical dimethyl hydrazine	< .250
n-Nitrosodimethylamine	101
Volatile Organics	
Benzene	N/A
Bromodichloromethane	N/A
Bromoform	N/A
Bromomethane	N/A
Carbon tetrachloride	N/A
Chlorobenzene	N/A
Chloroethane	N/A
2-Chloroethylvinyl ether	N/A
Chloroform	N/A
Chloromethane	N/A
Dibromochloromethane	N/A
Dichlorodifluoromethane	N/A
1,1-Dichloroethane	N/A
1,2-Dichloroethane	N/A
1,1-Dichloroethene	N/A
1,2-Dichloroethenes (cis & trans)	N/A
1,2-Dichloropropane	N/A
1,3-Dichloropropene	N/A
Ethylbenzene	N/A
Methylene chloride	N/A
1,1,2,2-Tetrachloroethane	N/A
Tetrachloroethene	N/A
Toluene	N/A
1,1,1-Trichloroethane	N/A
1,1,2-Trichloroethane	N/A
Trichloroethene	N/A
Trichlorofluoromethane	N/A
Vinyl chloride	N/A
1,2-Dichlorobenzene	N/A
1,3-Dichlorobenzene	N/A
1,4-Dichlorobenzene	N/A

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A10: Batch 6 Investigative Sample Results - Full-Scale Startup Testing Program[1]

Site Identification	IRAH-14-I	IRAH-20-E
Sampling Date	03/29/90	04/01/90
Treatment time (in hours)	0.0	51.5
Hydrazine Fuel Compounds/NDMA		
Hydrazine	51000	< .250
Monomethyl hydrazine	64000	1.40
Unsymmetrical dimethyl hydrazine	56000	< .250
n-Nitrosodimethylamine	40000	25.8
Volatile Organics		
Benzene	< 250	< 50.0
Bromodichloromethane	< 100	< 20.0
Bromoform	< 100	< 20.0
Bromomethane	< 100	< 20.0
Carbon tetrachloride	< 100	< 20.0
Chlorobenzene	< 100	< 20.0
Chloroethane	< 100	< 20.0
2-Chloroethylvinyl ether	< 100	< 20.0
Chloroform	< 100	< 20.0
Chloromethane	< 100	< 20.0
Dibromochloromethane	< 100	< 20.0
Dichlorodifluoromethane	< 100	< 20.0
1,1-Dichloroethane	< 100	< 20.0
1,2-Dichloroethane	< 100	< 20.0
1,1-Dichloroethene	< 100	< 20.0
1,2-Dichloroethenes (cis & trans)	< 100	< 20.0
1,2-Dichloropropane	< 100	< 20.0
1,3-Dichloropropene	< 100	< 20.0
Ethylbenzene	< 250	< 50.0
Methylene chloride	< 100	< 20.0
1,1,2,2-Tetrachloroethane	< 100	< 20.0
Tetrachloroethene	< 100	< 20.0
Toluene	< 250	< 50.0
1,1,1-Trichloroethane	< 100	< 20.0
1,1,2-Trichloroethane	< 100	< 20.0
Trichloroethene	< 100	< 20.0
Trichlorofluoromethane	< 100	< 20.0
Vinyl chloride	< 100	< 20.0
1,2-Dichlorobenzene	< 100	< 20.0
1,3-Dichlorobenzene	< 100	< 20.0
1,4-Dichlorobenzene	< 100	< 20.0

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A11: Batch 7 Investigative Sample Results - Full-Scale Startup Testing Program[1]

Site Identification	IRAH-15-I	IRAH-23-E
Sampling Date	04/01/90	04/04/90
Treatment time (in hours)	0.0	68.5
Hydrazine Fuel Compounds/NDMA		
Hydrazine	490000	< .250
Monomethyl hydrazine	180000	< .250
Unsymmetrical dimethyl hydrazine	940000	< .250
n-Nitrosodimethylamine	28300	1.39
Volatile Organics		
Benzene	< 250	< 50.0
Bromodichloromethane	< 100	< 20.0
Bromoform	< 100	< 20.0
Bromomethane	< 100	< 20.0
Carbon tetrachloride	< 100	< 20.0
Chlorobenzene	< 100	< 20.0
Chloroethane	< 100	< 20.0
2-Chloroethylvinyl ether	< 100	< 20.0
Chloroform	< 100	< 20.0
Chloromethane	< 100	< 20.0
Dibromochloromethane	< 100	< 20.0
Dichlorodifluoromethane	< 100	< 20.0
1,1-Dichloroethane	< 100	< 20.0
1,2-Dichloroethane	< 100	< 20.0
1,1-Dichloroethene	< 100	< 20.0
1,2-Dichloroethenes (cis & trans)	< 100	< 20.0
1,2-Dichloropropane	< 100	< 20.0
1,3-Dichloropropene	< 100	< 20.0
Ethylbenzene	< 250	< 50.0
Methylene chloride	< 100	< 20.0
1,1,2,2-Tetrachloroethane	< 100	< 20.0
Tetrachloroethene	< 100	< 20.0
Toluene	< 250	< 50.0
1,1,1-Trichloroethane	< 100	< 20.0
1,1,2-Trichloroethane	< 100	< 20.0
Trichloroethene	< 100	< 20.0
Trichlorofluoromethane	< 100	< 20.0
Vinyl chloride	< 100	< 20.0
1,2-Dichlorobenzene	< 100	< 20.0
1,3-Dichlorobenzene	< 100	< 20.0
1,4-Dichlorobenzene	< 100	< 20.0

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A12: Batch 8 Investigative Sample Results - Full-Scale Startup Testing Program[1]

Site Identification	IRAH-16-I	IRAH-24-E
Sampling Date	04/19/90	04/20/90
Treatment time (in hours)	0.0	33.5
Hydrazine Fuel Compounds/NDMA		
Hydrazine	650000	< .250
Monomethyl hydrazine	110000	< .250
Unsymmetrical dimethyl hydrazine	2000000	< .250
n-Nitrosodimethylamine	3800	6.30
Volatile Organics		
Benzene	N/A	N/A
Bromodichloromethane	N/A	N/A
Bromoform	N/A	N/A
Bromomethane	N/A	N/A
Carbon tetrachloride	N/A	N/A
Chlorobenzene	N/A	N/A
Chloroethane	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A
Chloroform	N/A	N/A
Chloromethane	N/A	N/A
Dibromochloromethane	N/A	N/A
Dichlorodifluoromethane	N/A	N/A
1,1-Dichloroethane	N/A	N/A
1,2-Dichloroethane	N/A	N/A
1,1-Dichloroethene	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A
1,2-Dichloropropane	N/A	N/A
1,3-Dichloropropene	N/A	N/A
Ethylbenzene	N/A	N/A
Methylene chloride	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A
Tetrachloroethene	N/A	N/A
Toluene	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A
Trichloroethene	N/A	N/A
Trichlorofluoromethane	N/A	N/A
Vinyl chloride	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Table A13: Batch 9 Investigative Sample Results - Full-Scale Startup Testing Program[1]
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Site Identification	IRAH-17-I	IRAH-27-KB	IRAH-28-KB	IRAH-29-KB	IRAH-30-KB
Sampling Date	05/01/90	05/01/90	05/01/90	05/01/90	05/01/90
Treatment time (in hours)	0.0	1.9	3.2	4.7	8.1
Hydrazine Fuel Compounds/NDMA					
Hydrazine	650	39.0	5.60	2.50	< 2.50
Monomethyl hydrazine	2600	3300	1000	3500	400
Unsymmetrical dimethyl hydrazine	500	82.0	3.10	2.70	< 2.50
n-Nitrosodimethylamine	66000	17200	4390	1090	25.0
Volatile Organics					
Benzene	< 50.0	N/A	N/A	N/A	N/A
Bromodichloromethane	< 20.0	N/A	N/A	N/A	N/A
Bromoform	< 20.0	N/A	N/A	N/A	N/A
Bromomethane	< 20.0	N/A	N/A	N/A	N/A
Carbon tetrachloride	< 20.0	N/A	N/A	N/A	N/A
Chlorobenzene	< 20.0	N/A	N/A	N/A	N/A
Chloroethane	< 20.0	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	< 20.0	N/A	N/A	N/A	N/A
Chloroform	43.0	N/A	N/A	N/A	N/A
Chloromethane	4900	N/A	N/A	N/A	N/A
Dibromochloromethane	< 20.0	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	< 20.0	N/A	N/A	N/A	N/A
1,1-Dichloroethane	< 20.0	N/A	N/A	N/A	N/A
1,2-Dichloroethane	< 20.0	N/A	N/A	N/A	N/A
1,1-Dichloroethene	< 20.0	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	< 20.0	N/A	N/A	N/A	N/A
1,2-Dichloropropane	< 20.0	N/A	N/A	N/A	N/A
1,3-Dichloropropene	< 20.0	N/A	N/A	N/A	N/A
Ethylbenzene	< 50.0	N/A	N/A	N/A	N/A
Methylene chloride	110	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	< 20.0	N/A	N/A	N/A	N/A
Tetrachloroethene	< 20.0	N/A	N/A	N/A	N/A
Toluene	120	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	< 20.0	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	< 20.0	N/A	N/A	N/A	N/A
Trichloroethene	< 20.0	N/A	N/A	N/A	N/A
Trichlorofluoromethane	< 20.0	N/A	N/A	N/A	N/A
Vinyl chloride	< 20.0	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	< 20.0	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	< 20.0	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	< 20.0	N/A	N/A	N/A	N/A

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Site Identification Sampling Date Treatment time (in hours)	IRAH-31-KB 05/01/90 10.2	IRAH-32-KB 05/01/90 12.1	IRAH-33-KB 05/01/90 14.1	IRAH-45-KB 05/02/90 15.6	IRAH-46-KA 05/02/90 18.1
Hydrazine Fuel Compounds/NDMA					
Hydrazine	< 2.50	< 2.50	< 2.50	< .250	N/A
Monomethyl hydrazine	1400	< 25.0	9.00	< 25.0	N/A
Unsymmetrical dimethyl hydrazine	< 2.50	< 2.50	< 2.50	1.10	N/A
n-Nitrosodimethylamine	22.0	18.5	5.21	8.30	1.07
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

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Site Identification	IRAH-47-KA	IRAH-48-KA	IRAH-49-KA	IRAH-50-KA	IRAH-51-KA
Sampling Date	05/02/90	05/02/90	05/02/90	05/02/90	05/02/90
Treatment time (in hours)	20.4	22.4	24.4	26.4	28.4
Hydrazine Fuel Compounds/NDMA					
Hydrazine	N/A	N/A	N/A	N/A	N/A
Monomethyl hydrazine	N/A	N/A	N/A	N/A	N/A
Unsymmetrical dimethyl hydrazine	N/A	N/A	N/A	N/A	N/A
n-Nitrosodimethylamine	3.59	5.70	2.21	.783	1.76
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobenzene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A13: (Page 4 of 5)

Site Identification	IRAH-52-KA	IRAH-53-KA	IRAH-54-KA	IRAH-55-KA	IRAH-56-KA
Sampling Date	05/02/90	05/03/90	05/03/90	05/03/90	05/03/90
Treatment time (in hours)	30.4	32.3	34.3	36.4	38.4
Hydrazine Fuel Compounds/NDMA					
Hydrazine	N/A	N/A	N/A	N/A	N/A
Monomethyl hydrazine	N/A	N/A	N/A	N/A	N/A
Unsymmetrical dimethyl hydrazine	N/A	N/A	N/A	N/A	N/A
n-Nitrosodimethylamine	5.78	8.36	5.21	5.92	6.19
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	N/A
Bromodichloromethane	N/A	N/A	N/A	N/A	N/A
Bromoform	N/A	N/A	N/A	N/A	N/A
Bromomethane	N/A	N/A	N/A	N/A	N/A
Carbon tetrachloride	N/A	N/A	N/A	N/A	N/A
Chlorobensene	N/A	N/A	N/A	N/A	N/A
Chloroethane	N/A	N/A	N/A	N/A	N/A
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	N/A
Chloroform	N/A	N/A	N/A	N/A	N/A
Chloromethane	N/A	N/A	N/A	N/A	N/A
Dibromochloromethane	N/A	N/A	N/A	N/A	N/A
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethane	N/A	N/A	N/A	N/A	N/A
1,1-Dichloroethene	N/A	N/A	N/A	N/A	N/A
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	N/A
1,2-Dichloropropane	N/A	N/A	N/A	N/A	N/A
1,3-Dichloropropene	N/A	N/A	N/A	N/A	N/A
Ethylbenzene	N/A	N/A	N/A	N/A	N/A
Methylene chloride	N/A	N/A	N/A	N/A	N/A
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	N/A
Tetrachloroethene	N/A	N/A	N/A	N/A	N/A
Toluene	N/A	N/A	N/A	N/A	N/A
1,1;1-Trichloroethane	N/A	N/A	N/A	N/A	N/A
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	N/A
Trichloroethene	N/A	N/A	N/A	N/A	N/A
Trichlorofluoromethane	N/A	N/A	N/A	N/A	N/A
Vinyl chloride	N/A	N/A	N/A	N/A	N/A
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	N/A

Table A13: (Page 5 of 5)

Site Identification Sampling Date Treatment time (in hours)	IRAH-57-KA 05/03/90 40.4	IRAH-58-KA 05/03/90 42.4	IRAH-59-KA 05/03/90 44.4	IRAH-60-KA 05/03/90 46.4	IRAH-25-E 05/01/90 53.0
Hydrazine Fuel Compounds/NDMA					
Hydrazine	N/A	N/A	N/A	N/A	< .250
Monomethyl hydrazine	N/A	N/A	N/A	N/A	< .250
Unsymmetrical dimethyl hydrazine	N/A	N/A	N/A	N/A	< .250
n-Nitrosodimethylamine	4.99	3.17	2.12	4.27	.572
Volatile Organics					
Benzene	N/A	N/A	N/A	N/A	< 50.0
Bromodichloromethane	N/A	N/A	N/A	N/A	< 20.0
Bromoform	N/A	N/A	N/A	N/A	< 20.0
Bromomethane	N/A	N/A	N/A	N/A	< 20.0
Carbon tetrachloride	N/A	N/A	N/A	N/A	< 20.0
Chlorobenzene	N/A	N/A	N/A	N/A	< 20.0
Chloroethane	N/A	N/A	N/A	N/A	< 20.0
2-Chloroethylvinyl ether	N/A	N/A	N/A	N/A	< 20.0
Chloroform	N/A	N/A	N/A	N/A	< 20.0
Chloromethane	N/A	N/A	N/A	N/A	< 20.0
Dibromochloromethane	N/A	N/A	N/A	N/A	< 20.0
Dichlorodifluoromethane	N/A	N/A	N/A	N/A	< 20.0
1,1-Dichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,1-Dichloroethene	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloroethenes (cis & trans)	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichloropropane	N/A	N/A	N/A	N/A	< 20.0
1,3-Dichloropropene	N/A	N/A	N/A	N/A	< 20.0
Ethylbenzene	N/A	N/A	N/A	N/A	< 50.0
Methylene chloride	N/A	N/A	N/A	N/A	< 20.0
1,1,2,2-Tetrachloroethane	N/A	N/A	N/A	N/A	< 20.0
Tetrachloroethene	N/A	N/A	N/A	N/A	< 20.0
Toluene	N/A	N/A	N/A	N/A	< 50.0
1,1,1-Trichloroethane	N/A	N/A	N/A	N/A	< 20.0
1,1,2-Trichloroethane	N/A	N/A	N/A	N/A	< 20.0
Trichloroethene	N/A	N/A	N/A	N/A	< 20.0
Trichlorofluoromethane	N/A	N/A	N/A	N/A	< 20.0
Vinyl chloride	N/A	N/A	N/A	N/A	< 20.0
1,2-Dichlorobenzene	N/A	N/A	N/A	N/A	< 20.0
1,3-Dichlorobenzene	N/A	N/A	N/A	N/A	< 20.0
1,4-Dichlorobenzene	N/A	N/A	N/A	N/A	< 20.0

[1] concentrations in micrograms per liter (µg/l)

< = not detected at or above method detection limit or method reporting limit
N/A = no analysis available
NDMA = n-nitrosodimethylamine

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Appendix B

AIR-MONITORING DATA

BATCHES 1 AND 2

Table B1: Batches 1 and 2 - ThermoSorb Cartridge Air-Monitoring Results
(Page 1 of 2)

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Batch 1					
01/11 - 12/90					
≈ 1500 - 0630					
T-101	2.4	NS	NS	NS	
T-301	2.0	0.008	0.0081U	0.0027U	
T-401	1.5	0.0059U	0.0081U	0.0027U	
P-201	3.3	0.014	0.0080U	0.0027U	
01/15/90					
≈ 0900 - 1201					
Above P-201	0.30	0.028U	0.055U	0.017U	Facility cleanup after Batch 1
Batch 1A					
01/19/90					
≈ 0900 - 1545					
T-101	0.55	NS	NS	NS	Transfer of wastewater from T-301 to T-201; no treatment
T-301	0.48	0.028	0.019U	0.0062U	Transfer of wastewater from T-301 to T-201; no treatment
P-201	0.30	0.035	0.018U	0.0062U	Transfer of wastewater from T-301 to T-201; no treatment
T-201 (top)	0.56	0.037	0.019U	0.0062U	Transfer of wastewater from T-301 to T-201; no treatment

Table B.1: (Page 2 of 2)

Location/time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Batch 2 01/29/90 ≈ 00830 -1830					
T-101	0.66	NS	NS	NS	
T-301	0.54	0.039	0.013U	0.0079U	
T-401	0.56	0.028	0.0083U	0.0050U	
P-201	0.62	0.028	0.0084U	0.0050U	

NDMA = n-nitrosodimethylamine
MMH = monomethyl hydrazine
UDMH = unsymmetrical dimethyl hydrazine
NS = not sampled
U = not detected; value given is the method detection limit
$\mu g/m^3$ = micrograms per cubic meter

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BATCHES 3 THROUGH 9

Table B2: ThermoSorb Cartridge Air-Monitoring Results
(Page 1 of 5)

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Pipe Repairs					
02/21/90 - 02/22/90 2000 - 0800	8.79	0.036U	0.016U	0.0099U	9-hour sample overnight following pipe repairs and cutting into hot lines
02/22/90 - 02/22/90 1115 - 1225	0.79	0.22	0.11U	0.071U	During cleanup following pipe repairs
No Treatment					
03/06/90 - 03/06/90 1140 - 1940	0.90	0.014U	0.022U	0.0052U	During transfer of wastewater back to US-4 and decontamination of facility
03/08/90 - 03/08/90 1200 - 1605	0.016	0.027U	0.043U	0.010U	After completion of facility decontamination following treatment of Batch 3; building ventilation on
03/08/90 - 03/09/90 1800 - 0800	2.4	0.018U	0.049	0.0063U	8-hour sampling period integrated over total time; no treatment; no ventilation
03/10/90 - 03/10/90 0800 - 1800	0.41	0.010U	0.045	0.0052U	8-hour sampling period integrated over total time; no treatment; no ventilation
03/10/90 - 03/11/90 1800 - 0600	0.44	0.010U	0.021U	0.0052U	8-hour sampling period integrated over total time; no treatment; no ventilation
03/12/90 - 03/12/90 0800 - 2000	0.074	0.010U	0.042	0.0052U	8-hour sampling period integrated over total time; no treatment; building open; ventilation off
03/13/90 - 03/13/90 0900 - 2100	1.4	0.010U	0.69	0.010U	8-hour sampling period integrated over total time; no treatment; building open

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Batch 3					
02/25/90 - 02/25/90 1100 - 2200	2.4	0.71	0.015U	0.013U	
02/25/90 - 02/26/90 2200 - 0800	0.26	0.018U	0.015U	0.013U	
02/26/90 - 02/29/90 1000 - 1800	0.21	0.018U	0.015U	0.013U	
02/26/90 - 02/27/90 1800 - 0200	1.89	0.052U	0.021U	0.021U	Reactor shut off at 1900 to repair pinhole leak in stainless-steel wastewater exit piping on reactor
02/27/90 - 02/28/90 0200 - 0830	1.85	0.12	0.026U	0.026U	No treatment overnight; reactor shut down
02/28/90 - 02/28/90 0800 - 1600	0.43	0.026U	0.016U	0.011U	
02/28/90 - 03/02/90 1600 - 2400	0.078	0.038U	0.017U	0.010U	
03/01/90 - 03/02/90 0930 - 0930	0.059	0.038U	0.017U	0.010U	8-hour sampling period integrated over 24 hours
03/02/90 - 03/03/90 0930 - 0930	0.12	0.038U	0.017U	0.010U	8-hour sampling period integrated over 24 hours
03/03/90 - 03/03/90 1132-1145	0.12U	NS	NS	NS	Sample location on outside window ledge on south side of hydrazine WWTF; sample location selected to evaluate potential airborne NDMA contamination during collection of final effluent sample for analysis
03/06/90 - 03/06/90 1140 - 1940	0.90	0.014U	0.022U	0.0052U	Pumping wastewater back to tank US-4; facility decontamination

Table B.2: (Page 3 of 5)

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Batch 4					
03/14/90 - 03/14/90 0830 - 1700	20	0.029U	4.3	0.016U	344-minute sampling period integrated over total time; radiometer plug failure on reactor at approximately 1300 hours
03/14/90 - 03/14/90 1030 - 1720	38	0.32	2.5	0.16	By recycle pump P-201; radiometer plug failure on reactor at approximately 1300 hours
03/15/90 - 03/15/90 0900 - 1555	23	0.012U	0.52	0.012U	Batch 4 treatment started at 0810; building open
03/15/90 - 03/15/90 1615 - 2210	0.28	0.019U	0.069	0.0093U	In sample packaging area in decontamination trailor; treatment samples from Batch 4 in refrigerator; no samples being packaged
03/15/90 - 03/16/90 2012 - 0700	0.10	0.017U	0.056	0.0084U	During Batch 4; hydrazine fuels sampling terminated at 0605 hours
03/19/90 - 03/20/90 1900 - 0700	0.15	0.011U	0.055U	0.0063U	8-hour sampling period integrated over 12 hours; following completion of Batch 4; building closed
Batch 5					
03/21/90 - 03/21/90 0830 - 2030	2.9	0.013U	0.029U	0.0052U	8-hour sampling period integrated over 12 hours; pretreatment of Batch 5
03/22/90 - 03/22/90 0800 - 2000	2.9	0.013U	0.029U	0.0052U	8-hour sampling period integrated over 12 hours; Batch 5 treatment started at 0947 hours
03/22/90 - 03/22/90 1155 - 1715	0.26	NS	NS	NS	3 feet outside west equipment bay during Batch 5 treatment
03/22/90 - 03/23/90 2000 - 0800	0.075	0.013U	0.029U	0.0052U	8-hour sampling period integrated over 12 hours; Batch 5 treatment

Table B.2: (Page 4 of 5)

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
03/23/90 - 03/23/90 0830 - 1948	0.085	0.013U	0.031U	0.056U	7.5-hour sampling period; Batch 5 treatment
03/23/90 - 03/24/90 2000 - 0800	0.036	0.013U	0.029U	0.0052U	8-hour sampling period integrated over 12 hours; power failure at approximately 2200 hours on 03/23/90; no overnight treatment of Batch 5
Batch 6					
03/29/90 - 03/29/90 0830 - 2030	1.7	0.019U	0.054U	0.016U	8-hour sample integrated over 12 hours; Batch 6 started at 0950 hours; building open
3/29/90 - 03/30/90 2030 - 0830	0.11	0.019U	0.054U	0.016U	8-hour sample integrated over 12 hours; Batch 6 treatment
3/30/90 - 3/30/90 0830 - 1630	0.043	0.015U	0.017U	0.010U	8-hour sample; Batch 6 treatment
03/30/90 - 03/31/90 1700 - 0800	0.038	0.015U	0.017U	0.010U	8-hour sample integrated over 15 hours; Batch 6 treatment
Batch 7					
04/02/90 - 04/02/90 0830 - 1630	0.34	0.015U	0.017U	0.010U	Batch 7 treatment started at 1200 hours, 04/01/90; building open
04/02/90 - 04/03/90 1700 - 0800	0.32	0.063U	0.075U	0.021U	8-hour sample; Batch 7 treatment
04/03/90 - 04/03/90 0923 - 1617	0.006U	0.012U	0.018U	0.024U	On concrete containment wall north of tank HAS-2

Table B.2: (Page 5 of 5)

Location/Time	Air Concentration ($\mu g/m^3$) NDMA	Hydrazine	MMH	UDMH	Comments/Activities
Batch 9					
05/01/90 - 05/01/90 0800 - 2000	0.62	NS	NS	NS	8-hour sample integrated over 12 hours; Batch 9 treatment
05/01/90 - 05/02/90 2000 - 0800	0.038	NS	NS	NS	8-hour sample integrated over 12 hours; Batch 9 treatment
05/02/90 - 05/02/90 0800 - 2800	0.028	NS	NS	NS	8-hour sample integrated over 12 hours; Batch 9 treatment
05/02/90 - 05/03/90 2000 - 0800	0.026	NS	NS	NS	8-hour sample integrated over 12 hours; Batch 9 treatment
05/03/90 - 05/03/90 0800 - 2000	0.020	NS	NS	NS	8-hour sample integrated over 12 hours; Batch 9 treatment

NDMA = n-nitrosodimethylamine
MMH = monomethyl hydrazine
UDMH = unsymmetrical dimethyl hydrazine
U = not detected; value given is the method detection limit
NS = not sampled
$\mu g/m^3$ = micrograms per cubic meter

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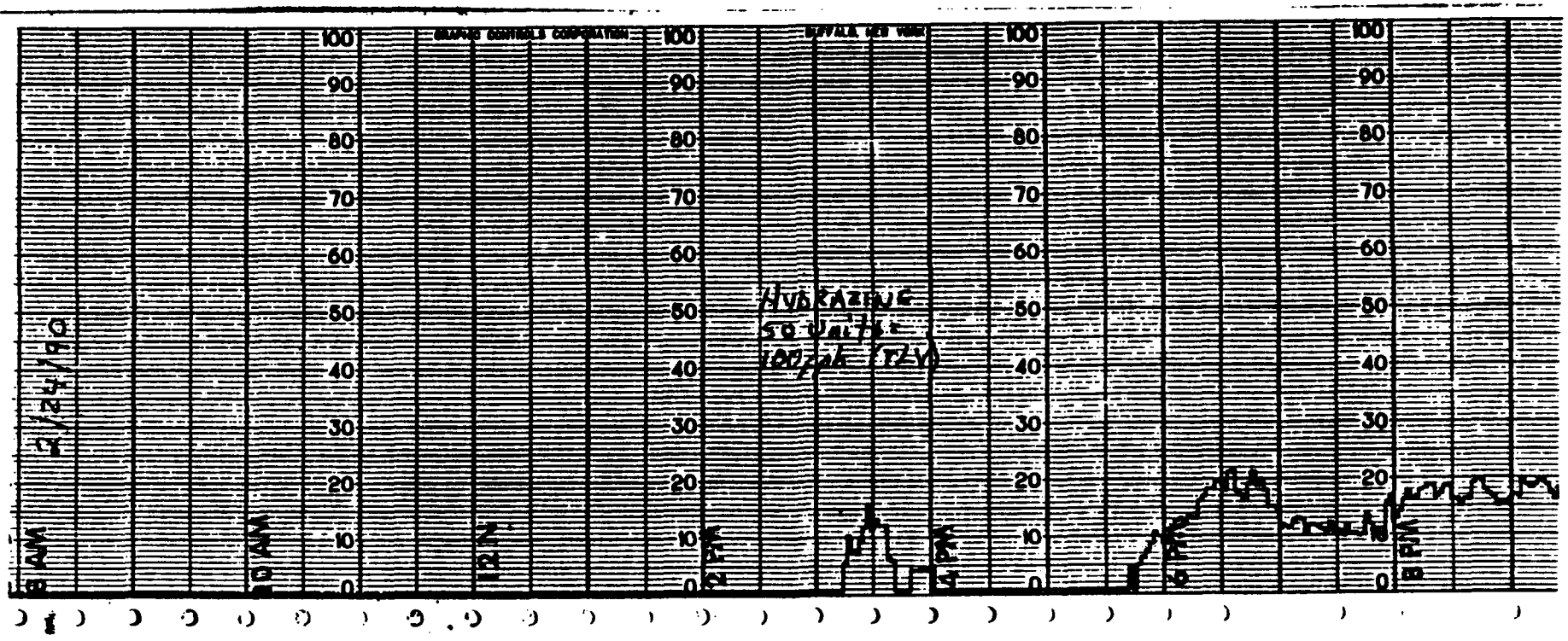
CONTINUOUS AIR-MONITORING RECORDS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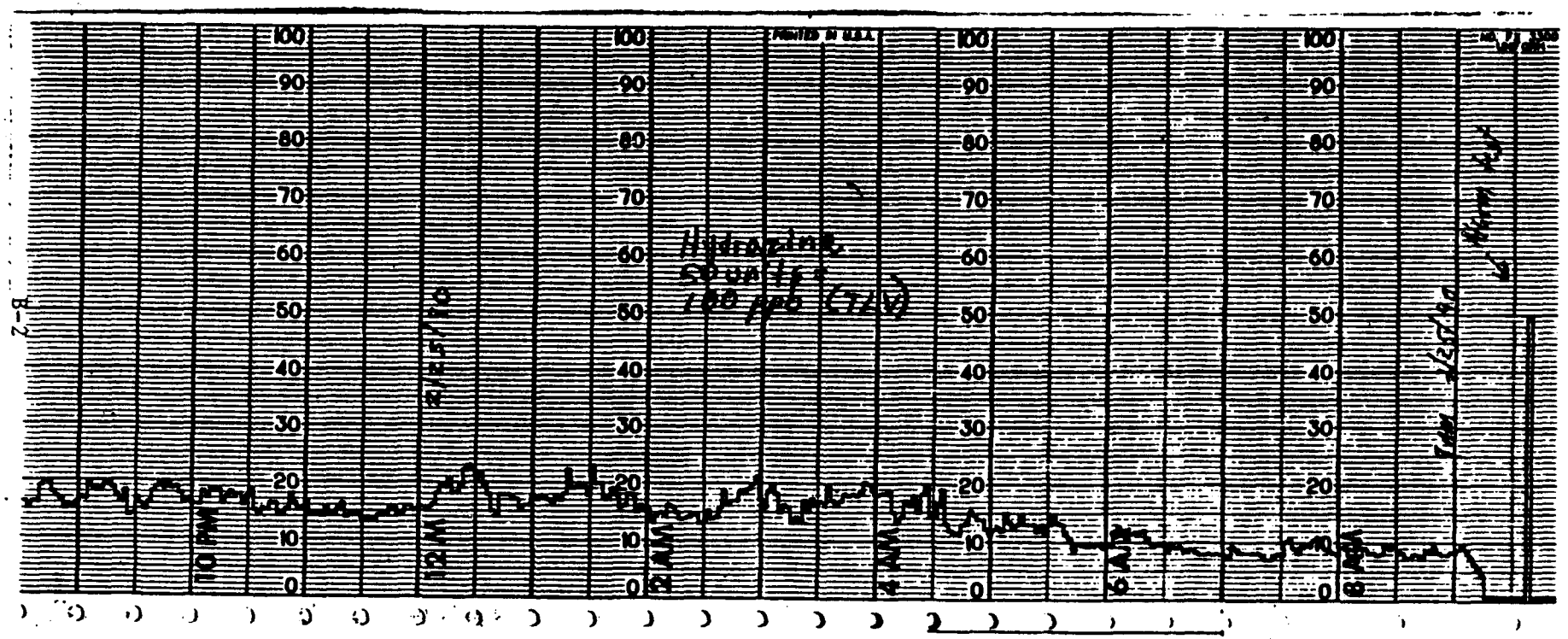
100 μA (FSD)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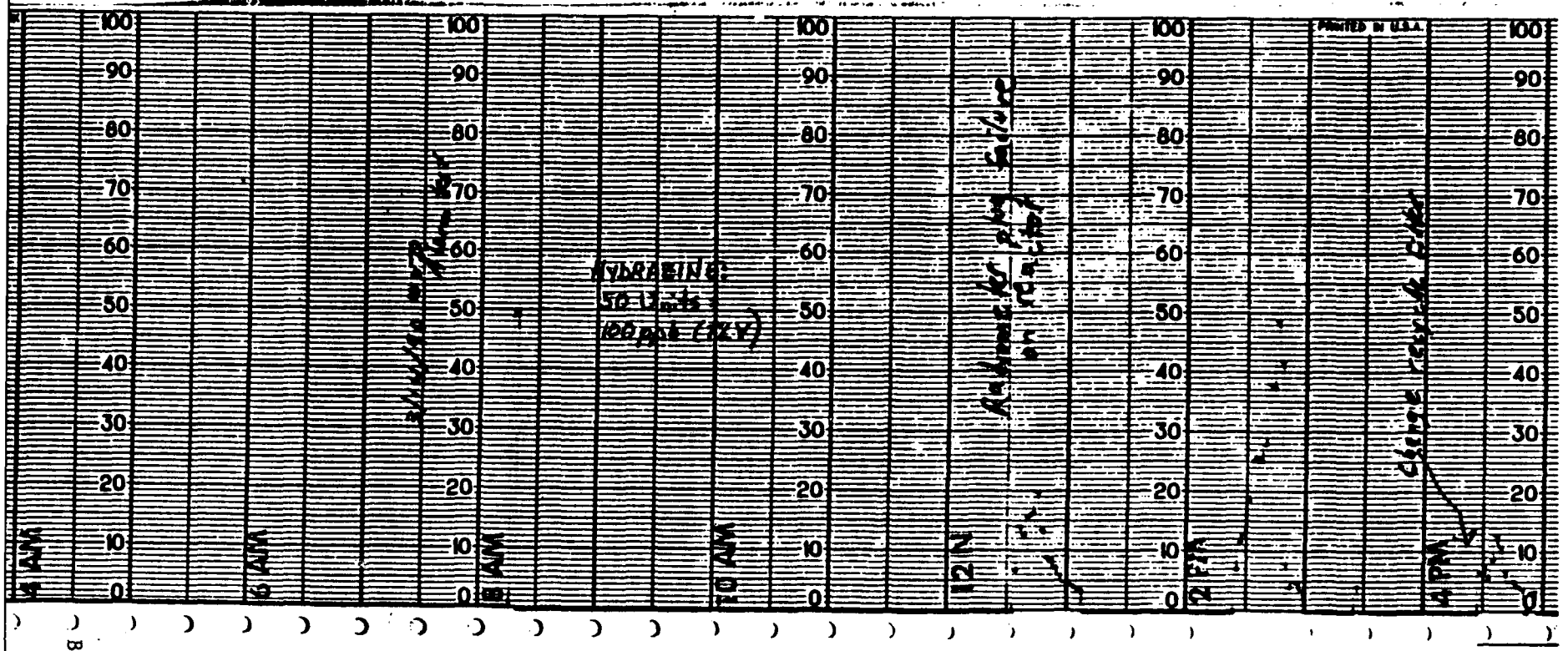
70
60
50
40
30
20
10
0
Hydrazine
50 units =
100 ppb (v/v)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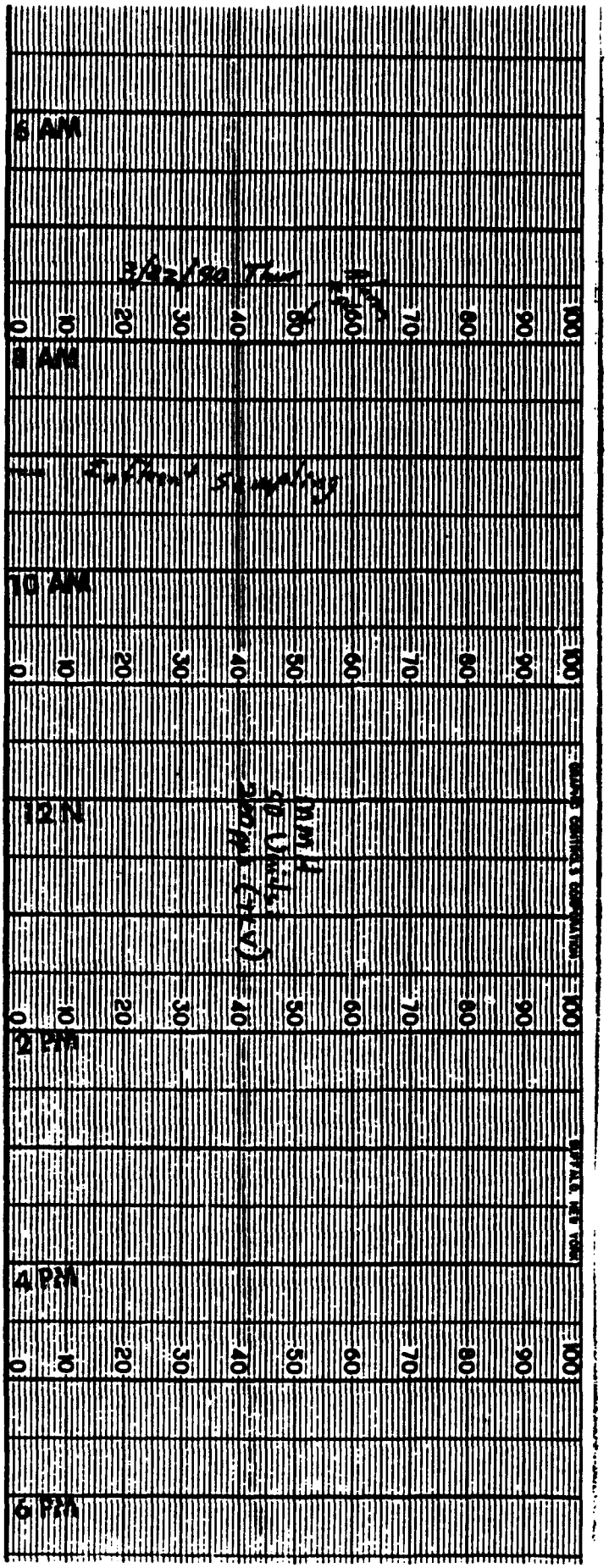
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